
ENGINEERS
PROCEEDINGS
35¹
1916
RECAP

PROCEEDINGS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS

21446

Vol. XXXV Number 1

JANUARY, 1916

Meeting in New York, January 14, 1916

MIDWINTER CONVENTION

FEBRUARY 8-9, 1916

The fourth Midwinter Convention of the Institute will be held in the Engineering Societies Building, 25-33 West 39th Street, New York, February 8-9, 1916.

The Institute convention will be followed by a convention of the Illuminating Engineering Society, in the same building, on February 10-11, 1916.

These dates were decided upon by co-operation of the two societies, for the convenience of members of either society who desire to attend the technical sessions and other events of both conventions, for which cordial invitations have been exchanged by the societies. Interesting programs of technical sessions and other features are being arranged and will be announced later.

PROCEEDINGS

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American Institute of Electrical Engineers

Vol. XXXV
Number 1

JANUARY, 1916

Per Copy $1.00
Per Year $10.00

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Entered as matter of the second class at the Post office, New York, N. Y., December 17, 1904, under the Act of Congress, March 3, 1879.

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Published monthly by the A. I. E. E. at 33 West 39th St., New York,

UNDER THE SUPERVISION OF THE EDITING COMMITTEE.

GEORGE R. METCALFE, Editor

Subscription. $10.00 per year for all countries to which the bulk rate of postage applies. All other countries $12.00 per year. Single copies $1.00. Subscriptions must begin with January issue.

Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXV
Number 2

FEBRUARY, 1916

Per Copy $1.00
Per Year $10.00

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PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXV
Number 3

MARCH, 1916

Per Copy $1.00
Per Year $10.00

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PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXV
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APRIL, 1916

Per Copy $1.00
Per Year $10.00

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PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXV
Number 5

MAY, 1916

Per Copy $1.00
Per Year $10.00

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American Institute of Electrical Engineers

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JUNE, 1916

Per Copy $1.00
Per Year $10.00

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXV | JANUARY, 1916 | Number 1

MEETING IN NEW YORK, JANUARY 14, 1916

The 317th meeting of the American Institute of Electrical Engineers will be held in the Engineering Societies Building, 33 West 39th Street, New York, on Friday, January 14, 1916, at 8:15 p.m.

Dr. Steinmetz will be the speaker of the evening and will present a paper entitled " Outline of Theory of Impulse Currents," in which he shows that from the integral of the general differential equation of the electric circuit, all types of electric currents are derived as special cases corresponding to particular values of the integration constants. In presenting this subject Dr. Steinmetz will supplement the printed paper by an explanation of the general subject as fully as the time will permit.

NOMINATIONS FOR INSTITUTE OFFICERS FOR 1916-17

As provided in Section 18 of the Institute by-laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1916, by the petition or by the separate endorsement in writing, of not less than fifty members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1916. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available.

The officers to be elected are: a President and a Treasurer, for the term of one year each, three Vice-Presidents for the term of two years each, and four Managers for the term of three years each.

For the information of members, the full text of Section 18 of the by-laws, governing the proposal of candidates for nomination, is printed below:

SEC. 18. In addition to the names of the incumbents of office, the Secretary shall publish on 'the form showing offices to be filled at the ensuing annual election in May,' provided for in Article VI, Section 30, of the Constitution, the names as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty members, received by the Secretary of the Institute in writing by January 25 of each year.

ANNUAL MEETING OF THE SOCIETY OF AUTOMOBILE ENGINEERS, JANUARY 5-6, 1916

The annual meeting of the Society of Automobile Engineers is to be held in New York, in the Engineering Societies Building, on January 5 and 6, 1916. The Society has extended to members of the American Institute of Electrical Engineers a special invitation to attend the morning and afternoon sessions on Thursday, January 6, beginning at 9:30 and 1:30 o'clock respectively, when papers will be presented on the subjects of steel, and electrical applications on gasoline automo-

biles. These sessions will be held in the auditorium of the building.

At the morning session, the addresses of President William H. VanDervoort and of the president-elect will be followed by the presentation of a paper by Dr. J. S. Unger on "The Effect of Sulphur Content in Steel," embodying the results of comprehensive tests of steel of various properties, showing the effect of impurity content of various amounts in rolled, forged or annealed steels, and a paper by Mr. Henry Schroeder on "Electric Bulbs for Automobiles."

At the afternoon session, Messrs. Alexander Churchward, Dr. R. H. Cunningham, Frank Conrad and Francis R. Hoyt will take part in a debate on "Battery versus Magneto Ignition," and Mr. Joseph Bijur will present a paper on "Electric Lighting and Starting."

Guests will be requested to present themselves at the registration bureau before entering the auditorium in order that they may be properly identified.

A. I. E. E. MEMBERSHIP

The question "Why should one join the A. I. E. E.?" is one often repeated. It is the intention of the Membership Committee to print in the PROCEEDINGS from time to time some answers which may assist those contemplating membership to determine the effect of such alliance.

The above question usually takes the form of "What will I get out of it?" That is a very natural and practical interrogation, capable of satisfactory answer, but, to the mind of the writer, should be subordinated to that suggested by a higher motive, which should prompt us in some of the more serious things of life.

The first thought that actuates the opinion of the writer is this:

The A. I. E. E. is the recognized leading society of the electrical industry in this country. Among its eight thousand members it numbers many of the leading engineers. It sets the technical and ethical standards of the profession, and by its many activities constantly lifts the standing of the electrical engineer and his work to a higher plane. All engaged in this engineering pursuit directly and indirectly benefit thereby. Should not each one, then, consider it a pleasant duty to join the Institute and contribute his share in extending this work? The gratification resulting from thus fulfilling one's obligations will then be followed by an experience which will afford a satisfactory answer to the question "What can I get out of the A. I. E. E.?"

WALTER A. HALL,
Chairman, Membership Committee.

THE NEW YORK CONFERENCE ON THE NATIONAL ELECTRICAL SAFETY CODE

A notable conference was held in the headquarters of the Institute, beginning October 25, 1915, and lasting two weeks, on the National Electrical Safety Code which has been prepared by the Bureau of Standards. It had been expected that a conference would be held in Washington, beginning October 27, at which delegates were to attend from the American Institute of Electrical Engineers, the National Electric Light Association, the American Electric Railway Association, the telephone interests, the fire and casualty insurance interests, the state industrial and public service commissions, several of the larger cities, the International Brotherhood of Electrical Workers, the National Safety Council, and a considerable number of engineers representing groups of utility companies with which the representatives of the Bureau of Standards had held conferences in different parts of the country. The expectation was that this conference would discuss and amend the code as presented by the Bureau, and then approve it for use, the recommendation of the Bureau being that for the first year the code be adopted on trial, subject to amendment at the end of the

year. However, at the urgent request of the Board of Directors of the American Institute of Electrical Engineers, of the National Electrical Light Association, and the Association of Edison Illuminating Companies, the Bureau postponed the Washington conference and held instead a conference with representatives of the various utilities that are affected by the code and of some of the electrical manufacturers. The object of this conference was to enable a thorough study of the code to be made in conjunction with the representatives of the Bureau of Standards, by representatives from various parts of the country of the electric light and power companies, the steam and electric railways, the telephone and telegraph companies, and the manufacturers. The delegates included those previously appointed by the engineering societies to attend the Washington conference, together with a large number of others selected to give the best representation possible for the different parts of the country and the different interests. Six engineers from the Pacific coast came east especially to attend the conference, one of whom represented the California Industrial Accident Commission, which has been cooperating with the Bureau in the preparation of the code. Eighty-five persons in all attended the sessions, a majority of whom remained through the entire conference.

The conference consisted of general sessions held daily from 9:30 to 1 o'clock. There were four main committees, one for each of the four main divisions of the code. Each committee discussed the rules of its part of the code very thoroughly, and reported to the main conference its approval of the rules as written or amendments agreed upon. The main conference received and discussed the partial reports of the several committees as presented daily, and in many cases went thoroughly into the details of the rules. An earnest effort was made to secu e unanimous agreement in every case, and this was generally accomplished. The representatives of the Bureau of Standards attended and participated in the discussions of the committees as well as the main conference, the latter being presided over by the Chief Physicist of the Bureau of Standards.

The conference was characterized by good feeling and the spirit of cooperation. Naturally there was much difference of opinion among the delegates on some of the rules, due to so many different interests and so many parts of the country being represented, and also to the fact that individual experiences differ greatly even in the same industry and in the same locality. Discussion on such rules brought out fully the reasons for and against the rules. In some cases such discussion established the rule more firmly than before; in other cases it resulted in modifying it, and occasionally even in eliminating it altogether. The discussions were in the highest degree educational, both to the delegates and to the representatives of the Bureau of Standards, and tended to remove very largely any differences of opinion existing at the beginning of the conference as to the need or advantage of having a national code that should be prepared by a national agency with the cooperation of all the interests affected, rather than local or state codes or codes prepared by individual societies. The discussion also emphasized the fact that such a safety code as the Bureau of Standards has prepared is far-reaching in its influence, amounting in many respects to a standardization of electrical construction and operation, and as such comprehensive rules cannot be expected to apply generally without exception in special cases, they should not be enforced in an arbitrary or mechanical fashion. On the other hand, the best results will be obtained by giving the commissions as well as the utilities time to become thoroughly familiar with the provisions of the code, and by having competent and experienced electrical engineers employed by such commissions as undertake to

inspect the central stations and substations, and overhead and underground lines of the utility companies. So far as installations on the premises of consumers are concerned, their inspection will generally require a different experience and less technical knowledge. It is expected that such inspections will be made by electrical inspection departments already established by the underwriters and many municipalities, as well as by the inspection departments of state industrial commissions.

The changes agreed upon in the code at the New York conference were in nearly every case acceptable to the Bureau of Standards, and the Bureau regards the code as very much improved by the conference. However, there were some changes proposed regarding strength of construction which require some further investigation before a final decision can be reached, and the Bureau is studying these questions now. One of the most important questions concerns the different grades of construction that shall be specified for different climatic conditions. In some sections of the country the conditions as to wind and ice are very mild as compared with extreme conditions of the northern and northeastern part of the country. Hence it is necessary to provide for graded requirements not only to cover different degrees of hazard or factors of safety, but also to cover different conditions of loading due to various weather conditions for the same factors of safety. The Bureau has worked out since the New York conference a simple method of expressing the requirements for all these varying conditions, which will shortly be submitted to the conference committee representing the various electrical engineering societies.

It is expected that the code as revised will shortly be submitted to the interests not represented at the New York conference, and then printed and distributed for general discussion and criticism prior to being finally approved for use by utility companies, insurance interests, municipalities, and state commissions.

E. B. Rosa

Washington, Dec. 20, 1915.

VANCOUVER SECTION'S PROGRAM

The Vancouver, B. C., Section's program for the remaining part of the 1915-16 season includes four meetings, with papers to be read as follows:

January 14, 1916. "Industrial Power Applications." (A. I. E. E. Industrial Power Committee lecture).

February 17, 1916. "The City of Kamloops Power Plant and Pumping Station," by Mr. H. K. Dutcher, Mem. Canadian Soc. C. E.

March 16, 1916. "Electric Dredging and Hydraulic Sluicing," by Mr. F. D. Nims, Fel. A. I. E. E.

April 13, 1916. "Water Powers of British Columbia," by Mr. G. R. G. Conway, Mem. Canadian Soc. C. E.

The meetings in February, March and April will be held jointly with the Vancouver Branch of the Canadian Society of Civil Engineers. The headquarters of the Section are in Room 1017, Metropolitan Building, Vancouver, B. C.

RESEARCH FELLOWSHIPS OPEN IN THE ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS

The University of Illinois has since 1907 maintained ten Research Fellowships in the Engineering Experiment Station, and in March, 1915, four additional fellowships were created. These fellowships, for each of which there is an annual stipend of $500, are open to graduates of approved American and foreign universities and technical schools. Appointments are for two consecutive collegiate years, at the expiration of which period, if all requirements have been met, the Master's degree will be granted. Not more than half the time

of the Research Fellows is required in connection with the work of the department to which they are assigned, the remainder being available for graduate study.

Nominations to fellowships are made each year from applications received by the Director of the Station not later than the first day of February. Appointments are made in March, and take effect the first day of the following September. There will be five vacancies to be filled at the close of the current academic year. Further information may be obtained by addressing the Director of the Engineering Experiment Station, University of Illinois, Urbana, Illinois.

A. I. E. E. MEETING IN NEW YORK, DECEMBER 10, 1915

The 316th meeting of the American Institute of Electrical Engineers was held in the Engineering Societies Building, New York, on Friday, December 10, 1915, beginning at 8:15 p. m.

President John J. Carty called the meeting to order, and introduced Mr. C. D. Knight, who presented his paper, entitled *The Principles and Systems of Electric Motor Control.* Those who took part in the discussion were Messrs. Bassett Jones, Edwin J. Murphy, W. I. Slichter, F. B. Crocker, J. A. Albrecht, H. F. Stratton, M. D. Goodman, Selby Haar, F. W. Gay, and C. D. Knight.

At the close of the discussion the meeting was adjourned, and most of those present accepted the invitation which had been extended to them to attend the joint meeting of the National Electric Light Association and the New York Electrical Society which was still in session in the auditorium of the Engineering Societies Building. The program included a most interesting demonstration of some twelve of the best electrically driven piano players and vocal and instrumental music by well-known artists.

DIRECTORS' MEETING, NEW YORK, DECEMBER 10 AND 11, 1915

The Board of Directors of the Institute held its regular monthly meeting in New York on Friday, December 10, 1915, at 3:30 p.m.

There were present: President John J. Carty, New York; Past Presidents C. O. Mailloux, New York, and Paul M. Lincoln, Pittsburgh, Pa.; Vice-Presidents Farley Osgood, Newark, N. J.; C. A. Adams, Cambridge, Mass.; J. Franklin Stevens, Philadelphia, Pa.; Managers H. A. Lardner, San Francisco, Cal., B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y., Bancroft Gherardi, New York, A. S. McAllister, New York, John H. Finney, Washington, D. C., C. E. Skinner, Pittsburgh, Pa., F. B. Jewett, New York, John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $8,707.28 was ratified.

Announcement was made of the appointment by President Carty of Prof. W. I. Slichter as a member of the Board of Examiners to succeed Prof. Albert F. Ganz, who resigned, and of Mr. A. S. Loizeaux as chairman of the Power Stations Committee to succeed Mr. C. F. Uebelacker, who resigned the chairmanship but continues a member of the committee.

Upon the recommendation of the Meetings and Papers Committee a two-day Midwinter Convention was authorized, to be held in New York on February 8 and 9, 1916.

Upon the request of the Seattle Section, and with the concurrence of the other Pacific Coast Sections, and the Meetings and Papers Committee, a Pacific Coast Convention was authorized, to be held in Seattle, Washington, on a date to be decided upon by the Seattle Section.

Upon the recommendation of the

Board of Examiners, three Associates were transferred to the grade of Member, six applicants were elected to the grade of Member, and 46 to the grade of Associate, and 136 students were ordered enrolled, in accordance with the lists published in this issue of the PROCEEDINGS.

Announcement was made of the expiration on the fourth Thursday of January, 1916, of the term of Mr. Charles E. Scribner as one of the Institute's three representatives upon the Board of Trustees of the United Engineering Society. Dr. Samuel Sheldon, who is chairman of the Library Board of the United Engineering Society, was appointed by the Board of Directors to succeed Mr. Scribner, for the three-year term ending on the fourth Thursday in January, 1919.

The meeting adjourned at 6:00 p.m. until Saturday, December 11, at 2:00 p.m.

The Board held an adjourned meeting on Saturday, December 11, 1915, at 2:00 p.m., at which a preliminary report of the Constitutional Revision Committee was considered. This report embodied the committee's recommendations for amendments to the Constitution after consideration of the replies received from members of the Board of Directors, the past-presidents, members of the Sections Committee, including the chairmen of Sections, and the membership at large, all of whom had been invited to make suggestions to the committee.

The proposed amendments were discussed by the Board at length and the actions taken were referred to the Constitutional Revision Committee, with the understanding that the committee would submit a complete report at the January meeting.

The meeting adjourned at 6:15 p. m. Those present were: President John J. Carty; Past-President C. O. Mailloux; Vice-Presidents C. A. Adams, J. Franklin Stevens, William McClellan; Managers H. A. Lardner, B. A. Behrend, L. T. Robinson, Bancroft Gherardi, A. S. McAllister, John H. Finney, F. B. Jewett, John B. Taylor, and Secretary F. L. Hutchinson.

A considerable amount of other business was transacted at these two meetings, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

PAST SECTION MEETINGS

Baltimore.—November 19, 1915, Physical Laboratory, Johns Hopkins University. Papers: (1) "The Combined Operation of Steam and Hydraulic Power in the Pennsylvania Water and Power Company's System," by J. A. Walls; (2) "Construction Elements of the Tallulah Falls Development," by C. G. Adsit. Attendance 30.

December 9, 1915, Physical Laboratory, Johns Hopkins University. Subject: Rates. Paper: "Rates and Rate Making," by P. M. Lincoln. Attendance 62.

Chicago.—October 26, 1915, Fullerton Hall. Address by Dr. Charles P. Steinmetz on "Illumination" Attendance 475.

November 22, 1915, Sherman Hotel. Paper: "Regulation of Public Utilities," by Leonard A. Busby. Attendance 164.

Cleveland.—November 30, 1915, Chamber of Commerce. Papers: (1) "The Value of Geological Survey Data to Engineers," by N. C. Grover; (2) "What the U. S. Weather Bureau in California is Doing for the Benefit of the Engineer," by Wm. H. Alexander. Meeting of Cleveland Engineering Society, members of Cleveland Section attended as guests.

Denver.—November 20, 1915, Denver Athletic Club. Address by Mr. W. A. Carter on "Electrical System of the Denver Gas and Electric Light Company." Prof. J. C. Roberts gave an outline of the new Chair of Safety and Efficiency at the Colorado School of Mines. Attendance 32.

Detroit-Ann Arbor.—November 6, 1915, Ann Arbor. Paper: "Marginal Economics," by John Parker. Attendance 31.

December 11, 1915, Detroit Engineering Society Hall. Paper: "Electric Energy—Wholesale and Retail," by Alexander Dow. Attendance 100.

Fort Wayne.—December 16, 1915, Fort Wayne Electric Works. Demonstration by Mr. Hall of some recent laboratory experiments in lighting.

Indianapolis-Lafayette.— November 26, 1915, Indianapolis. Paper: "The Electric Automobile and Its Sphere in Automobile Transportation," by W. C. Johnson. Attendance 51.

Ithaca.—November 19, 1915, Franklin Hall, Cornell University. Paper: "Construction Elements of the Tallulah Falls Development," by Charles G. Adsit. Demonstration of new oscillograph by C. B. Bennett. Attendance 55.

December 3, 1915, Franklin Hall, Cornell University. Electrical display held in connection with electrical prosperity week celebration. Attendance 500.

December 17, 1915, Franklin Hall, Cornell University. Discussion on "Industrial Applications and Characteristics of Electric Motors." Attendance 55.

Los Angeles.—November 20, 1915, Chamber of Commerce Building. Paper: "Insulators and Insulator Testing," by A. O. Austin. Attendance 69.

Lynn.—November 17, 1915. Illustrated lecture by Mr. H. H. Barnes, Jr., on "How New York Gets Its Electric Light and Power." Attendance 310.

December 1, 1915, General Electric Works. Address by Mr. J. W. Powell on "American Shipbuilding." Mr. Powell closed his address by showing many interesting views of submarines under course of construction. Attendance 325.

December 8, 1915, General Electric Works. Illustrated address by Mr. F. P. Cox on "Recent Developments in Meters and Instruments." Attendance 240.

Milwaukee.—November 10, 1915, Wisconsin Hotel. Paper: "High-Pressure Boiler Design," by Robert Cramer. Meeting under auspices of local section A. S. M. E. Attendance 90.

December 3, 1915, Republican House. Illustrated lecture by Prof. S. W. Parr on "Development in the Marketing of Coal—Specifications, Storage, etc." Attendance 75.

Minnesota.—December 13, 1915, Old Heidelberg Cafe. Paper: "District Steam Heating in Conjunction with Central Station Operation," by H. C. Kimbrough. Attendance 26.

Pittsfield.—November 18, 1915, Hotel Wendell. Illustrated address by Prof. R. A. Fessenden on "Submarine Signaling." Attendance 120.

Rochester.—November 26, 1915, Rochester Engineering Society Rooms. Lecture by Prof. W. S. Franklin on "Mechanical Analogies of Electricity and Magnetism." Attendance 74.

Schenectady.—November 2, 1915, Edison Club Hall. Joint smoker with members of the Edison Club; election returns were received and motion pictures shown. Attendance 500.

November 16, 1915, Edison Club Hall Paper: "Electric Furnaces," by John A. Seede. Attendance 200.

December 8, 1915, Edison Club Hall. Address by Mr. Oscar T. Crosby on "An Armed International Court and Preparedness." Attendance 325.

Seattle.—November 17, 1915, Chamber of Commerce. Address by Mr. R. H. Marriott on "The History and Development of Radiotelegraphy." Attendance 30.

Spokane.—November 19, 1915. Washington Water Power Company Building. Illustrated addresses as follows—(1) "Agricultural," by C. C. Thorn; (2) "The Philippines," by A. M. Wilson. Attendance 39.

St. Louis.—December 8, 1915, Engineers Club. Paper: "The Electric Steel Furnace," by W. L. Berry. Election of officers as follows—chairman

W. O. Pennell; secretary-treasurer, George McD. Johns. Attendance 48.

Toledo.—December 15, 1915, Toledo University. Address by Mr. Sewell Wright on "Radiotelegraphy." Attendance 40.

Vancouver.—November 25, 1915, Board of Trade Rooms. Paper: "The Electric Vehicle and the Central Station," by W. H. R. Fraser. Joint meeting with local branch of National Electric Light Association. Attendance 46.

Washington.—November 9, 1915, Cosmos Club. Paper: "Recent Developments in Rotary Converters," by J. L. Yardley. Attendance 49.

PAST BRANCH MEETINGS

University of Arkansas.—November 8, 1915. Lecture by Mr. Snodgrass on "Student Apprentice Course with the General Electric Company." Attendance 9.

November 16, 1915. Paper: "Transformer Test for Finding Short Circuits in Armatures," by P. X. Rice. Motion pictures showing construction of motors. Attendance 17.

Armour Institute.—November 30, 1915. Paper: "The Business Aspects of Engineering," by W. S. Taussig. Attendance 33.

Bucknell University.—November 15, 1915, Electrical Laboratory. Talk on "Micarta Insulation," by Mr. Sanders. Discussion on insulation in general by Prof. Rhodes. Attendance 21.

November 29, 1915, Electrical Laboratory. Illustrated address by Mr. F. O. Schnure on "The Power Plants of the Public Service Corporation of New Jersey." Attendance 22.

University of California.—October 20, 1915. Address by Mr. Swering on "Hydroelectric Systems." Attendance 18.

November 10, 1915. Papers by Messrs. Fronmuller and McFarland on "Voltage Regulation." Attendance 17.

University of Cincinnati.—December 7, 1915. Paper: "Shades and Reflectors," by H. Swindell and R. Ralph. Attendance 40.

University of Colorado.—December 9, 1915. Paper: "Electricity as Applied to the Mining of Precious Metals," by G. H. Horton. Attendance 36.

Highland Park College.—November 18, 1915, College Chapel. Address by Dr. G. Walter on "Keokuk Dam, and the Success of an Engineer." Attendance 47.

December 1, 1915, Electric Laboratory. Address by Mr. C. F. Wright on "Mechanical and Human Efficiencies." Attendance 25.

Iowa State College.—November 17, 1915, Ames, Iowa. Address by Mr. E. K. Lewison on "The History and Development of the Storage Battery." Attendance 24.

December 1, 1915. Address by Prof. H. R. O'Brien on "Technical Journalism." Attendance 23.

University of Kansas.—December 15, 1915, Marvin Hall. Messrs. Putnam and Madden gave a review of the recent inspection trip taken by the seniors. Mr. V. B. Hunt gave a short talk. Attendance 26.

State University of Kentucky.—November 12, 1915, Mechanical Hall. Papers: (1) "Municipal Cooperation in Public Utility Management;" (2) "Recent Results Obtained from the Preservation Treatment of Telephone Poles;" (3) "The Engineering Experiment Station of the University of Illinois." Attendance 24.

December 17, 1915, Mechanical Hall. Papers: (1) "Electrical Porcelain;" (2) "Fixation of Atmospheric Nitrogen;" (3) "Line Disturbances Caused by Special Squirrel Cage and Wound-Rotor Motors when Starting Elevators and Hoists." Attendance 24.

Lafayette College.—November 6, 1915, Pardee Hall. Papers: (1) "The Norfolk and Western Electrification;" (2) "Artificial Daylight;" (3) "Electric Welding." Attendance 20.

November 13, 1915. Paper: "The Thury System of Direct-Current Transmission." Attendance 18.

November 20, 1915. Papers: (1) "Phasing Devices on the Norfolk and Western Railroad;" (2) "Plastic Insulation;" (3) "Slate as an Insulator;" (4) "A 5000-h.p. Chain Drive;" (5) "Induction Meters." Attendance 20.

Lehigh University.—November 18, 1915, Physical Laboratory. Papers: (1) "The Development of the Nitrogen-Filled Lamp," by H. M. Fry; (2) "Methods of Detecting Grounds," by S. E. Heisler. Attendance 47.

University of Maine.—December 15, 1915, Hannibal Hamlin Hall Addresses by Prof. Barrows, Prof. Childs and Mr. James. Attendance 35.

University of Michigan.—November 18, 1915, Engineering Building. Paper: "Heating Appliances," by Archie Oakes. Attendance 17.

University of Missouri.—November 15, 1915, Engineering Building. Papers: (1) "The Life and Work of Mr. Edison," by Professor Weinbach; (2) "Development of the Incandescent Lamp," by Mr. Dulaney. Attendance 36.

November 29, 1915. Paper: "The Diesel Engine for Generator Drive," by L. R. Golladay. Attendance 29.

December 14, 1915. Paper: "Electric Devices for Automobiles," by S. H. Anderson. Attendance 26.

University of Nebraska.—November 3, 1915, Electrical Laboratory. Paper: "The Developments in Electrical Engineering," by F. C. Holtz Attendance 31.

December 1st, 1915. Short addresses as follows—(1) "Isolated Electric Power Plants or Farm Plants," by Mr. Hall; (2) "Relative Cost of Electric and Acetylene Light," by Mr. Eldred; (3) "Household Electric Appliances," by Mr. Fee. Attendance 25.

North Carolina College of Agricultural and Mechanical Arts.—December 8, 1915, West Raleigh. Election of officers as follows—president, R. V. Davis; vice-president, F. A. Baker; secretary-treasurer, R. L. Kelly. Attendance 23.

Ohio Northern University.—December 8, 1915, Dukes Memorial. Paper: "Commutation Troubles Due to the Use of Carbon Brushes." Talk by Mr. Gilbert on "The Use of Electricity in the Elimination of Smoke." Attendance 24.

Ohio State University.—December 3, 1915, Robinson Laboratory. Address by Mr. R. G. Lockett on "The Testing of Electric Rail Bonds." Attendance 31.

December 13, 1915. Paper: "The Relations of Theory and Practise," by P. Trombetta. Attendance 26.

University of Oklahoma.—November 17, 1915, Norman. Papers: (1) "Relation of the Engineering Schools of the State to the Profession, the State, and the Public;" (2) "Effect of Hydroelectric Power Transmission upon the Social and Economic Conditions of the United States;" (3) "Results of Preservative Treatment of Telephone Poles;" (4) "Thury System of Direct-Current Transmission." Attendance 18.

Oregon Agricultural College.—December 2, 1915, Corvallis. Paper: "The Rosenberg Generator." Attendance 20.

Purdue University.—November 22, 1915, Electric Building. Illustrated lecture on "The Manufacture of Steel Pipe." Joint meeting with local section of A. S. M. E. Attendance 222.

December 14, 1915, Electric Building. Addresses on "Apprenticeship Courses" by Professor C. Francis Harding, D. D. Ewing and Mr. L. L. Bouton. Attendance 205.

Rensselaer Polytechnic Institute.—November 16, 1915. Paper: "Industrial Power," by Kenneth P. Applegate. Attendance 63.

Stanford University.—November 18, 1915, High-Voltage Laboratory. Address and demonstration by Prof. Harris J. Ryan on "High-Voltage and High-Frequency Phenomena." Attendance 31.

Syracuse University.—November 18, 1915. Paper: "Continuous Waves in Long-Distance Radiotelegraphy." Attendance 12.

December 2, 1915. Paper: "Electric Traction," by E. J. Gibbons. Attendance 16.

December 16, 1915. Paper: "Industrial Motor Control," by Edward S. Sheahan. Attendance 50.

Virginia Polytechnic Institute.—November 19, 1915, Blacksburg, Va. Illustrated address by Mr. John W. Crowley on "The Application Engineer." Attendance 86.

Washington University.—December 9, St. Louis, Mo. Address by Mr. S. N. Clarkson on "The Thury System of Direct-Current Distribution". Attendance 35.

University of Washington.—December 7, 1915, Forestry Building. Papers: (1) "Appraisal Work for the Seattle Electric Company;" (2) "Modern Telephony;" (3) "Localizing Long-Distance Line Trouble." Attendance 32.

Worcester Polytechnic Institute.—November 19, 1915, Electrical Engineering Hall. Address by Mr. Willard Hall on "Application of Electricity in the Home." Four reels of moving pictures were shown illustrating the address. Attendance 260.

Yale University.—November 22, 1915, Electrical Engineering Laboratory. Paper: "Long-Distance Power Transmission," by Harold W. Buck. Attendance 100.

December 10, 1915. Paper: "The Electrical Inspector at Work," by Thomas H. Day. Mr. Day showed lantern slides illustrating faulty conditions which have caused fires, also a number of actual wires, fittings, fuses, etc., by which fires have been caused. Attendance 110.

PERSONAL

Mr. Frank B. Dunn, formerly an electrical engineer with the Western Electric Company, having completed his post-graduate work in Ohio State University, has returned to China and is connected with the Hunan Telephone Company as engineer in charge of plant department.

Mr. Edward N. Lake, formerly in charge of the Chicago office of the Stone and Webster Engineering Corporation, has become a partner in the Krehbiel Company, engineers and constructors, with offices in the Marquette Building, Chicago.

OBITUARY

William Weeden Cole, Mem. A. I. E. E., consulting engineer and member of the firm of Cole, Ives and Davidson, of New York, died at Poughkeepsie, N. Y., December 20, 1915. Mr. Cole was 48 years old and a graduate of Worcester Polytechnic Institute, class of 1887. After several years of railroad work in the West, Mr. Cole came to Boston as electrical superintendent of the West End Street Railroad. From 1892 to 1908 he was associated with the Elmira, N. Y., Water, Light and Railroad Company as vice-president and general manager. Later he became consulting engineer for Day and Zimmerman of Philadelphia and New York. Retiring from this connection, he opened a consulting office in New York in 1914, later becoming a member of the firm of Cole, Ives and Davidson. Mr. Cole was the first president of the Empire State Gas and Electric Association. He was elected an Associate of the Institute on April 25, 1902, and was transferred to the grade of Member on October 23, 1903.

William Claplin Andrews, Assoc. A. I. E. E., sales engineer and advertising manager of the Edison Storage Battery Company, died in New York City December 21, 1915. Mr. Andrews was graduated from Tufts College, and after some time spent in the testing department of the General Electric Company at Schenectady, N. Y., became connected with the Edison Lamp Works at Harrison, N. J. In 1909 he joined the Rae Company as secretary and as business manager of *Electrical Merchandise*, resigning in 1912 to become advertising manager of the Edi-

son Storage Battery Company. Mr. Andrews enjoyed a very large acquaintance among electrical men, and was very active in the work of the Electric Vehicle Association of America. He was elected an Associate of the Institute on May 21, 1895.

RECOMMENDED FOR TRANSFER DECEMBER 2, 1915

The Board of Examiners, at its regular monthly meeting on December 2, 1915, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filled at once with the Secretary.

To the Grade of Fellow

CROMWELL, LEWIS W., Electrical Engineer, American Zinc Co. of Tenn., Mascot, Tenn.

To the Grade of Member

DOGGETT, LEONARD A., Professor of Electrical Engineering, U. S. Naval Academy, Annapolis, Md.

PENROSE, CHARLES, Engineer in charge of Construction, Station "A-2", Philadelphia Electric Co., Philadelphia, Pa.

WIGERT, JOHN F., Designing Electrical Engineer, Homestake Mining Co., Lead, S. D.

TRANSFERRED TO THE GRADE OF MEMBER DECEMBER 10, 1915

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on December 10, 1915.

KENTISH-RANKIN, IVOR LIONEL, Testing Engineer, Commonwealth Edison Co., Chicago, Ill.

ONKEN, WILLIAM H., JR., Managing Editor, *Electrical World*, New York, N. Y.

OSBORNE, HAROLD S., Engineering Dept., American Tel. & Tel. Co., New York, N. Y.

MEMBERS ELECTED DECEMBER 10, 1915

CHAMPION, CHARLES S., Patent Lawyer, 2 Rector St., New York, N. Y.

FEIKER, FREDERICK MORRIS, Editor, *Electrical World*, New York; res., 152 Sycamore Ave., Mt. Vernon, N. Y.

HERSH, WALTER L., Supervisor, Power, Transmission, Panama Canal, Gatun, C. Z.

HORTON, WILLIAM HENRY, JR., Commercial Engineer, General Electric Co., 1st National Bank Bldg., Denver, Colo.

ROWELL, LEWIS D., Asst. Professor of Electrical Engineering, Purdue University; res., 111 Lutz Ave., W. Lafayette, Ind.

VAUGHAN, FRANK P., Manager Vaughan Electric Co., Ltd., 94 Germain St., St. John, N. B., Can.

ASSOCIATES ELECTED DECEMBER 10, 1915

ANDERSON, ALEXANDER COLIN, Engineer, Electrical Dept., Vickers Ltd., Broadway, Westminster, London, England.

ARTHUR, RAYMOND BARTEAU, Steam Tester, Williamsburg Power Station, Brooklyn Rapid Transit Co.; res., 1032 E. 10th St., Brooklyn, N. Y.

BEATON, MALCOLM J., Electrical Engineer, Ohio State Telephone Co., Canton, Ohio.

BLACKMORE, CHARLES THOMAS, Inspector, North East Electric Co.; res., 250 Frank St., Rochester, N. Y.

BORROUGHS, WALTER L., Assistant Sales Engineer, Electric Storage Battery Co.; res., 1753 W. 96th St., Chicago, Ill.

*BRENNEMAN, JESSE LAMAR, Professor of Electrical Engineering, University of New Mexico, Albuquerque, N. Mex.

BROWN, CARLETON MURRAY, Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Clover Club, Edgewood Park, Pa.

*BURLINGHAM, CHARLES S., JR., Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 517 Franklin Ave., Wilkinsburg, Pa.

CANDY, ALBERT M., General Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

DAVIS, WILLIAM RAY, Chief Electrician, Springfield Gas and Electric Co.; res., 1409 West Edwards St., Springfield, Ill.

DAWE, HENRY S., Electrical Engineer, Ashburton Electric Supply Co., Ltd., Burnett St., Ashburton, New Zealand.

DICKINSON, NEVILLE S., Instructor in Electricity Newark Technical School, Newark, N. J.

*EDEL, ALBERT FREDERICK, Electrical Engineer, Western Electric Co., 463 West St.; res., 1 Arden St., New York, N. Y.

*FECHT, ARTHUR JOHN, Research Engg. Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 835 Rebecca Ave., Wilkinsburg, Pa.

FISH, JOSEPH PRYOR, Electrical Draftsman, Stone & Webster Engineering Corp., Boston; res., 243 Belmont St., Brockton, Mass.

FOLTZ, THOMAS FRANKLIN, Electrical Engineer, Washington Terminal Co., Washington, D. C.

FRANKLIN, RAYMOND EARL, Superintendent, Electrical Dept., Yukon Gold Co., Dawson, Yukon Territory.

FREEHAFER, H. L., Specification Engineer, Mountain States Tel. & Tel. Co., Denver, Colo.

GERHARDT, CARL L., Engineer and Draftsman, Alabama Power Co., 940 Brown-Marx Building, Birmingham, Ala.

GHOSH, S., Chief Electrical Engineer, Tata Iron & Steel Co., Sakchi, India.

*GLEISS, FRANK J., Testing and General Efficiency, Pacific Gas & Electric Co., 226 Jessie St., San Francisco, Cal.

GUST, CEDRIC L., Foreman of Electrical Installation, Homestake Mining Co., Lead, S. D.

HAYDEN, CHARLES B., Assistant, Engineering Staff, Wisconsin Railroad Commission, Madison; res., Sun Prairie, Wis.

HASTINGS, ALBERT ANTHONY, Chief Engineer in Charge, Electrical Power Station; res., 117 Carlyle Street, Napier, New Zealand.

HAYMAN, WILLIAM CLAYTON, Wire and Cable Engineer, General Electric Co.; res., 19 Glenwood Blvd., Schenectady, N. Y.

JEFFE, EPHRAIM F., Senior, Brooklyn Polytechnic Institute; res., 216 Lewis Ave., Brooklyn, N. Y.

KNOWLES, RALPH ROY, Instructor in Physics and Electrical Engineering, Colorado State School of Mines; res., 1100 12th St., Golden, Colo.

KOBERG, MAX, Chief Electrician and Manager of Electrical Dept., Koberg & Echandi, San Jose, Costa Rica, C.A.

LOMONT, CLARENCE F., Electrical Engineer, with Harold Almert; res., 4555 Sheridan Road, Chicago, Ill.

LUBIENSKI, HENRY, Chief of Turbine Dept., Iron & Steel Works "Ludwig Nobel," Petrograd, Russia.

MARLOW, JAKOB AAGE, Chief Electrical Engineer, Power Station and Workshop, Siam Electricity Co., Ltd., Bangkok, Siam.

MERRY, GEORGE G., Electrical Engineer, 1100 White Building, Buffalo, N. Y.

MILLIGAN, A. W., Installation Superintendent, Mountain States Tel. & Tel. Co., Denver, Colo.

MORRILL, JOSEPH BRADLEY, Acting Professor of Electrical Engineering, University of Colorado; res., 983 14th St., Boulder, Colo.

*PALMER, STANLEY G., Instructor in Electrical Engineering, University of Nevada; res., 203 Mill St., Reno, Nev.

PARKER, SEPTIMUS, Operator, Pacific Gas & Electric Co., 226 Jessie St., San Francisco, Cal.

RICHARDSON, WILLIAM RUFUS, Wire and Cable Insulation Tester, Simplex Wire & Cable Co.; res., 100 Western Ave., Cambridge, Mass.

Riley, Harrie D. W., Jr., Railway Signal Engineer, Interstate Commerce Commission, Chattanooga, Tenn.

Seward, William Everett, Electrical Engineer, American Manufacturing Co.; res., 216 Guernsey St., Brooklyn, N. Y.

Shafer, William Leroy, Engineering Dept., Central District Tel. Co., 416 7th Ave., Pittsburgh, Pa.

Shoemaker, Joseph Jamison, Superintendent of Public Utilities, City Hall, Sibley, Iowa.

Stanley, Henry C., Engineering Dept., General Electric Co., San Francisco; res., 497 Forest St., Oakland, Cal.

Strout, Arthur P., Operator, Northern California Power Co. Cons., Manton, Cal.

Truesdell, James Warner, Assistant Chief Electrician, E. I. Du Pont Powder Co., Parlin, N. J.

Wickstrom, Arvid, Construction Foreman, General Electric Co., 1022 Monadnock Bldg., Chicago, Ill.

Woodward, Daniel Hook, Plant Dept., American Tel. & Tel. Co.; res., 79 W. Fifth St., Atlanta, Ga.

Total 46.

*Former enrolled Students.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before January 31, 1916.

Albrecht, H. C., Philadelphia, Pa.
Armstrong, G. E., Los Angeles, Cal.
Arndt, R., East St. Louis, Ill.
Ayars, W. S., Halifax, N. S.
Baily, T. F. (Member), Alliance, Ohio
Bartgis, C. P., New York, N. Y.
Bearce, E. F., Chillicothe, Ohio
Bland, A. M., Washington, D. C.
Boegehold, E. S., New York, N. Y.
Buchanan, W. B., Toronto, Ont.
Callahan, G. E., Bedford, Va.
Cameron, J. S., Milwaukee, Wis.
Canady, D. R., Cleveland, Ohio
Cousins, R. J., Bluestone, W. Va.
Cranston, H.D.(Member), Manila, P. I.
Davis, R. H., Spokane, Wash.
Davison, T. E., Schenectady, N. Y.
De Cou, B. S., Philadelphia, Pa.
Dobson, C. F., Great Falls, Mont.
Doherty, R. E., Schenectady, N. Y.
Donnohue, J. J., Salt Lake City, Utah
Edwards, G. D., New York, N. Y.
Evans, R. W., Akron, Ohio
Finkelnburg, E. H., Milwaukee, Wis.
Finley, R. B., Philadelphia, Pa.
Fisher, F. E., Elizabeth, N. J.
Fitzhugh, T. C., San Antonio, Tex.
Flansburg, P. L., Haskell, N. J.
Foulkrod, R., Philadelphia, Pa.
Francy, C. W., Steubenville, O.
Frost, W. H., New York, N. Y.
Gridley, S. D., Philadelphia, Pa.
Griffin, R. C., Oakland, Cal.
Gross, A. W., Schenectady, N. Y.
Hackensmith, I. C., Kansas City, Mo.
Hale, C. B., New York, N. Y.
Hardy, A. W., Oklahoma City, Okla.
Harris, C. B., Freewater, Ore.
Hayase, S., Tokyo, Japan
Henry, P. C., Gary, Ind.
Hess, L. J., Joliet, Ill.
Hill, C. G., Chicago, Ill.
Hobbs, M. H., Great Falls, Mont.
Hogg, C. J., Brookline, Mass.
Ide, C. E., Toledo, O.
Iida, T., Joliet, Ill.
James, W. G., Orono, Maine.
Jones, K. B., Schenectady, N. Y.
Kaase, W. E., New York, N. Y.
Keller, A., Cornucopia, Ore.
Kenworthy, B. L., Cohoes, N. Y.
Kopfer, W. B., Denver, Colo.
Lackie, W. W. (Fellow), Glasgow, Scotland.
Lull, L. C., Los Angeles, Cal.
Luther, G. D., Dever, Colo.
Markle, E. W., Hublersburg, Pa.

Moffatt, D. R., Detroit, Mich.
Monroe, E. A., Kansas City, Mo.
Morrisey, F. T., Winamac, Ind.
Munoz, C. M., New York, N. Y.
Nakayama, H., Tobata, Japan.
Nickenig, C. W., New York, N. Y.
Ormson, B. H., Whitcomb, Mont.
Palmer, J. C. R. (Member), New York, N. Y.
Pohlman, C. F., Indianapolis, Ind.
Pope, N. A., Rio de Janeiro, Brazil.
Poppe, T. W., Long Island City, N. Y.
Prince, D. C., Springfield, Ill.
Rich, A. R., Schenectady, N. Y.
Rogers, C. B., New York, N. Y.
Sachs, J. B., Berwick, Pa.
Sahm, P. A. B., New York, N. Y.
Schott, R. A. (Member), Charleston, W. Va.
Schwarting, H. F., St. Louis, Mo.
Sebast, F. M., Albany, N. Y.
Smith, M. B., Syracuse, N. Y.
Snyder, C. J., Omaha, Nebr.
Stetler, A. M., Rochester, N. Y.
Steward, J. L., Niagara Falls, N. Y.
Tappan, F. G., Ithaca, N. Y.
Takatori, T., New York, N. Y.
Terry, R. H., Milwaukee, Wis.
Thorne, H. O., New York, N. Y.
Tucker, B. F., Mattoon, Ill.
Vanderfield, E. W., Chicago, Ill.
Wall, R., Sacramento, Cal.
Winshurst, H. E. C., Elizabeth, N. J.
Winter, E. M., Ampere, N. J.
Yeh, T. S., Changsha, China.
Total 89.

STUDENTS ENROLLED DECEMBER 10, 1915

7645 Casey, J. G., Marquette Univ.
7646 Eddy, C. W., Mass. Inst. Tech.
7647 Stephan, W. H., Marquette Univ.
7648 Burger, E. E., Penna. State Coll.
7649 Miller, C. G., Mass. Inst. Tech.
7650 Rhoads, C. S., Jr., Purdue Univ.
7651 Brantley, E. P., Ga. Sch. Tech.
7652 Paden, R. S., Ga. School Tech.
7653 Francis, A. P., Ga. School Tech.
7654 Sellers, P. B., Jr., Ga. Sch. Tech.
7655 Large, S. R., Yale University.
7656 Reis, M. de O., Carnegie Inst. Tech.
7657 Thalheimer, J. J., Case Sch. App. Sci.
7658 Cammack, J. E., Catholic Univ. of America.
7659 Lewis, B. F., Bucknell University.
7660 Clarke, A. N., Univ. of Michigan.
7661 Pappe, R. D., Univ. of Michigan.
7662 Skutecki, J. W., Univ. of Mich.
7663 Sacia, C. F., Univ. of Michigan.
7664 Clark, J. F., Univ. of Michigan.
7665 Yokoyama, S., Univ. of Michigan.
7666 Miller, H. W., Univ. of Michigan.
7667 Rutgers, G. A., Univ. of Michigan.
7668 Price, J. M., Delaware College.
7669 Blumberg, L., Delaware College.
7670 Thien, E. J., Montana State Coll.
7671 Burke, J. J., Montana State Coll.
7672 Holmes, A., Mass. Inst. Tech.
7673 Wagstaff, R. H., Univ. of Kansas.
7674 Clarkson, F., Mass. Inst. Tech.
7675 Atchison, T. C., Mass. Inst. Tech.
7676 Sutherland, G., Mass. Inst. Tech.
7677 Eckley, W., Oregon State College.
7678 Kneale, R. M., Case Sch. App. Sci.
7679 Haskin, F., Univ. of Kansas.
7680 Sinks, V. H., Oregon Agri. Coll.
7681 Dana, Duncan, Mass. Inst. Tech.
7682 Turner, R. H., Univ. of Minn.
7683 Lawrence, S. W., Univ. of Minn.
7684 King, H., Casino Tech. Night Sch.
7685 Magee, F. L., Lehigh University.
7686 Ferens, R. A., Pratt Institute.
7687 Hooper, J. A., Oregon Agri. Coll.
7688 Bauer, R. G., Carnegie Inst. Tech.
7689 Deibel, M. J., Ohio North. Univ.
7690 Drake, C. J., Kansas University.
7691 Mickey, B. D., Penna. State Coll.
7692 Seibert, H. W., Ore. Agri. Coll.
7693 Webster, A. D., Syracuse Univ.
7694 Parmelee, R. H., Syracuse Univ.
7695 Kniskern, F. B., Syracuse Univ.
7696 Mellinger, M. C., Syracuse Univ.
7697 Nag, N. K., Univ. of Illinois.
7698 Littlefield, W. B., Mass. Inst. Tech.
7699 Martin, A., Mass. Inst. Tech.
7700 del Valle, F. A., Univ. of Mich.
7701 Taylor, D. W., Univ. of Michigan.
7702 Buell, H. C., Univ. of Michigan.
7703 Binder, A. A., Columbia Univ.
7704 Curry, W. A., Columbia Univ.
7705 Smilari, M. A., Columbia Univ.
7706 Williams, R. C., Columbia Univ.
7707 Kennedy, S. S., Columbia Univ.
7708 Carroll, P. L., Columbia Univ.
7709 Fenton, C. L., Univ. of Penna.

7710 Fitschen, J. H., Cooper Union.
7711 McKinley, H. W., Colo. Agri. Coll
7712 Cressman, C. S., Penna. St. Coll.
7713 Newcomb,T.,RensselaerPoly.Inst.
7714 Abrams, A. A., Univ. of Penna.
7715 Griffeth, C. L., Univ. of Kansas.
7716 Sykes, C. B., Univ. of Kansas.
7717 McKown, F. W., Mass. Inst. Tech.
7718 Butt, B. E., Bucknell University.
7719 Koch, J. R., Villanova College.
7720 Hall, G. W., Univ. of Texas.
7721 Beecroft, S. R., Univ. of Texas.
7722 Merrill, G. M., Univ. of Texas.
7723 Williamson, C. A., Univ. of Texas.
7724 Leeds, J. L., Univ. of Penna.
7725 Huntington, M. B., Cornell Univ.
7726 Roof, C. W., Cornell Univ.
7727 Funnell, C. L., Cornell Univ.
7728 Meyer, G. C., Cornell Univ.
7729 Wiesner, M. W., Cornell Univ.
7730 Grumman, L. R., Cornell Univ.
7731 Moore, J. H., Cornell Univ.
7732 McGuinness, W. V., Cornell Univ.
7733 Valade, E. A., Cornell Univ.
7734 Bason, G. F., Cornell Univ.
7735 Colle, H., Cornell Univ.
7736 Thomas, B., Jr., Cornell Univ.
7737 Barbour, D. L., Cornell Univ.
7738 McDermott, M. B., Cornell Univ.
7739 Congdon, C. H., Cornell Univ.
7740 Frisbie, W. Z., Cornell Univ.
7741 Naugle, J. F., Cornell Univ.
7742 Gahnkin, V. G., Cornell Univ.
7743 Allwein, A. F., Univ. of Penna.
7744 Baldwin, I. W., Yale University.
7745 Busch, R. E., Penna. State Coll.
7746 Tillotson, E. E., Univ. of Kansas.
7747 Reynolds, J. P., Case School of Applied Science.
7748 Purple, J. C., Univ. of Penna.
7749 Rider, E. E., Casino Technical Night School.
7750 Wilson, G. H., Jr., Villanova Coll.
7751 Yuronka, J. R., N. Y. Elec. Sch.
7752 Nott, G. E., Univ. of Toronto.
7753 Richmond, J., Univ. of Toronto.
7754 Amdursky, S. S., Syracuse Univ.
7755 O'Daniel, C., Univ. of Missouri.
7756 Hollister, F. H., Iowa St. Coll.
7757 Alden, H. B., Iowa State Coll.
7758 Blake, J. E., Iowa State Coll.
7759 Herom, A. J., Iowa State Coll.
7760 Rogers, B. A., Iowa State Coll.
7761 Landman, S. J., Iowa State Coll.
7762 Lamberty, J. J., Iowa State Coll.
7763 Rawlings, J. B., Iowa State Coll.
7764 Beck, G. E., Iowa State College.
7765 Burrill, P. J., Iowa State Coll.
7766 Mankin, H. A., Univ. of Mich.
7767 Kreiner, J. P., Univ. of Mich.
7768 Richardson, F. E., Univ. of Mich.
7769 Dolph, N. L., Univ. of Mich.
7770 Taylor, L. D., Univ. of Minn.
7771 Behr, H. R., Univ. of Illinois.
7772 Putnam, R. E. A., Univ. of Kans.
7773 Wilson, O. W., Stevens Inst. Tech.
7774 Weiss, C. G. A., N. Y. Elec. Sch.
7775 Weathersby, M., N. Y. Elec. Sch.
7776 Cheng-chih, L., Lehigh Univ.
7777 Klooz, W., Kans. State Agri. Coll.
7778 Bright, E. A. G., Yale University.
7779 Harwood,P.B.,Carnegie Inst.Tech.
7780 Subers, C. V. A., Univ. of Penna.

Total 136.

EMPLOYMENT DEPARTMENT

NOTE: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-89. Manufacturer of mechanical engineering equipment desires engineer with sales experience for New York City territory on salary basis. Please state experience, salary desired.

V-90. Vacancy for a man thoroughly familiar with all the details of manufacturing gauze wire brushes. Must know the machinery required. Excellent opportunity for the right man.

V-92. Salesman for New York State, familiar with single-phase motors and their application. Give age, height, weight, married or single, and past business history in confidence, also references.

The United States Civil Service Commission announces an open competitive examination for radio inspector, for men only (20 years of age or over), on January 19, 1916, to be held at numerous places in the United States. From the register of eligibles resulting from this examination, certification will be made to fill vacancies in the position of radio inspector and assistant radio inspector at salaries ranging from $1200 to $1600 a year.

The duties of radio inspectors will be primarily to inspect radio apparatus on steamships and they may also be called upon to examine radio operators. Assistant radio inspectors are required to assist the radio inspectors in the enforcement of the wireless communication laws and to carry 30 or 40 pounds of instruments.

Persons desiring this examination should at once apply for the circular announcing this examination (Form No. 65, issued Dec. 16) and Form No. 1312, stating the title of the examination for which the form is desired, to the U. S. Civil Service Commission, Washington, D. C., or to the Secretary of the Civil Service Board at the post office or custom house of any of the numerous places in the U. S. where the examination will be given.

MEN AVAILABLE

387. Commercial Engineer, with long experience in selling electrical and mechanical apparatus, and familiar with the design and operation of public utilities, would like to represent large manufacturing company in the Chicago district.

388. Electrical Engineer. Age 32, technical education, ten years' practical experience. Expert on management of construction and operation of electrical apparatus connected with large industrial plants. Can show efficiency with minimum cost and delay. Now connected in above capacity; location no object.

389. Electrical Engineer and Business Man. Exceptionally wide practical experience involving nearly every branch of the electrical field. Specialty—developing, manufacturing or exploiting new mechanical or electrical appliances, or improving upon the old. No trouble handling shop men or dealing with executives or outside concerns. Particularly difficult or unusual propositions solicited.

390. Distribution Engineer. Twenty years' experience in the design, construction and maintenance of underground distribution systems, desires a position with a company where first-class work will be appreciated, or will design and install systems on a commission basis.

391. A mechanical and electrical engineer of scientific training and of diversified experience in manufacturing and organization, now holding executive position with holding company, operating public utility properties, desires new position requiring exercise of business judgment and executive ability.

392. Mr. Corporation Manager, do you need an electrical executive? Are you satisfied with your electrical department's efficiency? An electrical

executive and power apparatus expert, technically trained along electrical and mechanical engineering lines and with considerable electrical engineering experience, would correspond relative to filling that vacancy or improving that efficiency.

393. Electrical Engineer, 1912 graduate. Has engaged in construction work in South America and in Europe until the outbreak of war. Since then has been associated with a consulting engineer in the design of small electric plants. Speaks Spanish fluently, and some German. Can accept position at once.

394. Mem. A. I. E. E., with 20 years' successful experience with two of the largest electrical companies, and for the past three years with the largest electrical installation of the times, desires position on construction or maintenance work. Will accept minimum salary pending development of work. Will invest capital under suitable contions. Correspondence invited.

395. Electric Power Rate Engineer. Expert in power cost and analysis, and in the preparation of the best revenue-producing schedules for central stations. At present in charge of the service and distribution department of a western company. Would like a position in the East.

396. Sales Engineer, active, alert, resourceful, must locate in Chicago. Is thoroughly experienced in selling controlling devices, power apparatus and transmission line materials. Must get Chicago agency for electrical equipment at once. Is confident of ability to sell any electrical apparatus requiring a high degree of salesmanship.

397. Research Engineer, graduate of one of the leading universities, will be available for new proposition on or after February first. Two years shop apprentice, one year testing department, and three years' drafting room experience with Westinghouse Co. Engaged in magnetic and electrical research investigations during last four years. Negotiations solicited.

398. Electrical Engineer, technical graduate, Mem. A. I. E. E., Assoc. Mem. A. S. C. E., with 16 years' practise, principally as superintendent of electric departments for large steel, copper and Portland cement companies. Employed at present but can leave on reasonable notice. Responsible position desired with large industrial or manfacturing company.

399. Technical Graduate. Age 29, American. Ten years' experience in electric lighting, power and railway construction and operation. Drafting, estimating and general office experience. Has been assistant superintendent of large interurban railway and power system. Underground cable and duct experience. Familiar with layout of steam and electrical equipment.

400. Electrical Engineer, technical graduate and post-graduate, age 28. Six years' experience in construction, research, drafting, extensive electrical, steam turbine and power plant testing, including two years of rotary converter design. Prefer position which requires executive ability. At present employed in the East; will go anywhere.

401. Technical Graduate, 1914, desires to begin at the bottom with reliable electrical concern. Eight months' test floor experience. Rocky Mountains or West preferred, but can go anywhere. Will consider any phase of electrical work, including teaching. Salary not a prime consideration. Single, age 25.

ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Code of Lighting Factories, Mills and other Work Places. Prepared by Committees of the Illuminating Engineering Society and issued under the direction of the Society. New York, 1915. (Gift of Illuminating Engineering Society.)

New Hampshire. Public Service Commission. Laws relating to the duties of the Public Service Commission. 1915. Concord, 1915, (Gift of Public Service Commission.)

New York State. Public Service Commission, Second District. Annual Report. 8th vol. II. Albany, 1915. (Gift of New York State Public Service Commission.)

Wallingford (Conn.) Board of Electrical Commissioners of the Borough Electric Works. Report for year ending July 31, 1915. Wallingford, 1915. (Gift of Alfred L. Pierce.)

GIFT OF MARYLAND PUBLIC SERVICE COMMISSION

——Case no. 690. Notes on Construction overheads, filed October 1, 1915. In the matter of the Chesapeake & Potomac Telephone Company of Baltimore City, investigation of rates and charges, property and affairs.

——Case no. 690. Notes on fair value, filed Oct. 1, 1915. In the matter of the Chesapeake & Potomac Telephone Company of Baltimore City—Rate Investigation.

——Case no. 690. Notes on Intangibles. In the matter of the Chesapeake and Potomac Telephone Company of Baltimore City—Rate Investigation.

——Case no. 690. Notes on Fair Return. In the matter of the Chesapeake and Potomac Telephone Company of Baltimore City—Rate Investigation.

UNITED ENGINEERING SOCIETY

Electric Railway. By A. M. Buck. New York, 1915. (Purchase.)

Electrical Instruments in Theory and Practice. By W. H. F. Murdoch and U. A. Oschwald. New York, Whittaker & Co., 1915. (Purchase.)

McGraw Electrical Directory—Lighting and Power Edition, October, 1915. New York, 1915. (Purchase.)

Public Utilities Reports, annotated. 1915-C. Rochester, N. Y., 1915. (Purchase.)

Rate Research. vols. 2-7. Chicago, 1912-15. (Purchase.)

Treatise on the Theory of Alternating Currents. Vol. I. Ed. 2. By A. Russell. Cambridge, 1914. (Purchase.)

Water Powers of Canada. The Maritime Provinces, Prince Edward Island, New Brunswick, N. S. By K. H. Smith.

——Prairie Provinces, Manitoba, Saskatchewan, Alberta. By P. H. Mitchell..

——Province of British Columbia. By G. R. G. Conway.

——Province of Ontario. By H. G. Acres.

——Province of Quebec. By F. T. Kaelin. (Gift of Mr. Challis.)

History and present state of electricity, with original experiments. By Joseph Priestley. London, 1767. (Purchase.)

Nebraska State Railway Commission to the Governor. Annual Report. 7th, 1914. Lincoln, 1915. (Gift of Nebraska Railway Commission.)

Principles of Direct Current Machines. By A. S. Langsdorf. New York, 1915. (Purchase.)

Public Utilities Reports, annotated. 1915 D. Rochester, 1915. (Purchase.)

Specifications covering the construction at crossings of overhead lines of public utilities. Prepared by a Joint Committee representing the different classes of utilities in interest and recommended to The Public Service Commission of the Commonwealth of Pennsylvania for adoption. Philadelphia, 1915. (Gift of Paul Spencer.)

GIFT OF ARTHUR WORISCHEK

Canter, O. Die Haus und Hotel Telegraphie. 1883. (Elektro-technische Bibliothek, Band 14.)

Elektro technische Bibliothek, vol. 4, 11, 14.

Hauck, W. Ph. Die galvanischen batterien. 1883. (Elektro-technische Bibliothek, Bd. IV.)

Montufar, M. de Manual de Telegrafia electrica. 1871.

Schwartze, T. Le Téléphone, le microphone et le radiophone. 1885.

von Urbanitzky, A. Die elektrischen beleuchtungs anlagen. 1883.

OFFICERS AND BOARD OF DIRECTORS, 1915-1916

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(Term expires July 31, 1916.)
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(Term expires July 31, 1916.)
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(Term expires July 31, 1917.)
P. M. LINCOLN.

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(Term expires July 31, 1916.)

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ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.

*Deceased.

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Revised to January 1, 1916

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Revised to January 1, 1916

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Revised to January 1, 1916

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L. L. Edgar, E. A. Wagner,
H. A. Hornor, John B. Whitehead,
A. G. Jones, F. E. Wynne.

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Ampere, N. J.
Ralph D. Mershon, Frank J. Sprague.

Term expires July 31, 1917.
A. E. Kennelly, Robert T. Lozier.
S. G. McMeen.

Term expires July 31, 1918.
H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.
Charles F. Brush, William Stanley,
N. W. Storer.

Term expires July 31, 1920.
Carl Hering, Harris J. Ryan,
H. G. Stott.

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Term expires July 31, 1916.
C. O. Mailloux, L. T. Robinson,
Farley Osgood.

Term expires July 31, 1917.
B. A. Behrend, Paul M. Lincoln,
William McClellan.

Ex-Officio.

John J. Carty, President.
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F. L. Hutchinson, Secretary.

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LIST OF SECTIONS

Revised to January 1, 1916.

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Atlanta................Jan. 19, '04	A. M. Schoen	
Baltimore.............Dec. 16, '04	J. B. Whitehead	L. M. Potts, Industrial Building, Baltimore, Md.
Boston..................Feb. 13, '03	L. L. Elden	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago.........................1893	W. J. Norton,	Taliaferro Milton, 613 Marquette Building, Chicago, Ill.
Cleveland.............Sept. 27, '07	E. H. Martindale	Irving H. Van Horn, National Lamp Works Nela Park, Cleveland, Ohio.
Denver................May 18, '15	W. A. Carter	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor.....Jan. 13, '11	Ralph Collamore	C. E. Wise, 427 Ford Bldg, Detroit, Mich.
Fort Wayne...........Aug. 14, '08	J. J. Kline	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Ind.
Indianapolis-Lafayette..Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca..................Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Los Angeles...........May 19, '08	E. Woodbury	R.H. Manahan, 32 City Hall, Los Angeles, Cal.
Lynn...................Aug. 22, '11	G. N. Chamberlin	F. S. Hall, General Electric Co., Lynn, Mass.
Madison...............Jan. 8, '09	M. C. Beebe	F. A. Kartak, Univ. of Wis. Madison, Wis.
Mexico.................Dec. 13, '07		
Milwaukee.............Feb. 11, '10	R. B. Williamson	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.............Apr. 7, '02	E. T. Street	Walter C. Beckjord, St. Paul Gas Light Co., St. Paul, Minn.
Panama................Oct. 10, '13	William H. Rose	C. W. Markham, Balboa Heights, C. Z.
Philadelphia...........Feb. 18, '03	J. H. Tracy	W. F. James, 14th Floor, Weidner Bldg., Philadelphia, Pa.
Pittsburgh............Oct. 13, '02	T. H. Schoepf,	G. C. Hecker, 436 Sixth Avenue, Pittsburgh, Pa.
Pittsfield..............Mar. 25, '04	M. O. Troy	F. R. Finch, General Electric Company, Pittsfield, Mass.
Portland, Ore..........May 18, '09	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Rochester.............Oct. 9, '14	E. L. Wilder	F. E. Haskell, 93 Monica Street Rochester, N. Y.
St. Louis..............Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco..........Dec. 23, '04	A. H. Babcock	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady...........Jan. 26, '03	L. T. Robinson	F.W. Peek, Jr., Gen. Elec. Co., Schenectady, N. Y.
Seattle.................Jan. 19, '04	C. E. Magnusson	C. E. Terrell, Puget Sound Trac. Lt. and Pr. Co., Seattle, Wash.
Spokane...............Feb. 14, '13	Victor H. Greisser	C. A. Lund, Washington Water Power Co., Spokane, Wash.
Toledo.................June 3, '07	George E. Kirk	Max Neuber, Cohen, Friedlander & Martin, Toledo, Ohio.
Toronto................Sept. 30, '03	D. H. McDougall	H. T. Case, Continental Life Building, Toronto, Ontario.
Urbana.................Nov. 25, '02	P. S. Biegler	T. D. Yensen, Univ. of Illinois, Urbana, Ill.
Vancouver.............Aug. 22, '11	R. F. Hayward	H. N. Keifer, Northern Electric Company, Ltd., Vancouver, B. C.
Washington, D. C......Apr. 9, '03	R. H. Dalgleish	Arthur Dunlop, National Electric Supply Company, Washington, D. C.

Total 32

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas.....Nov. 12, '09		
Alabama, Univ. of......Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of.....Mar. 25, '04	P. X. Rice	F. M. Ellington, University of Arkansas, Fayetteville, Ark.
Armour Institute........Feb. 26, '04	A. A. Oswald	J. F. Hillock, Armour Institute of Technology, Chicago, Ill.
Bucknell University....May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	J. V. Kimber	H. A. Mulvaney, 1521 Hopkins Street, Berkeley, Cal.
Carnegie Inst. of Tech..May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.....Apr. 10, '08	W. A. Steward	R. H. Kruse, 75th and Main Streets, Cincinnati, O.
Clarkson College of Tech..Dec. 10, '15		
Clemson Agricultural College................Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College.........Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized.		Chairman	Secretary.
Colorado, Univ. of......	Dec. 16, '04	E. F. Peterson	Samuel J. Blythe, University of Colorado, Boulder, Colo.
Georgia School of Technology...............	June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College..	Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.........	June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College......	Apr. 15, '03	Frank H. Hollister	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of..........	May 18, '09		A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...	Jan. 10, '08	L. V. Fickle	Clarence E. Reid, Kansas State Agric. Col., Manhattan, Kan.
Kansas, Univ. of........	Mar. 18, '08	E. C. Arnold	E. C. Burke, 1214 Kentucky Street, Lawrence, Kansas.
Kentucky State, Univ. of	Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College.......	Apr. 5, '12	Rodman Fox	Frank H. Schlough, Lafayette College, Easton, Pa.
Lehigh University.......	Oct. 15, '02	A. F. Hess	R. W. Wiesman, Lehigh University, South Bethlehem, Pa.
Lewis Institute.........	Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of.........	Dec. 26, '06	A. A. Packard	E. V. Crimmin, Univ. of Maine, Orono, Me.
Michigan, Univ. of......	Mar. 25, '04	U. M. Smith	N. F. Brown, University of Michigan, Ann Arbor, Mich.
Missouri, Univ. of......	Jan. 10, '03	K. Atkinson,	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col......	May 21, '07	Taylor Lescher	J. A. Thaler Montana State College, Bozeman, Mont.
Nebraska, Univ. of......	Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A. Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts......	Feb. 11, '10	R. V. Davis	R. L. Kelly, West Raleigh, N. C.
North Carolina, Univ. of	Oct. 9, '14	P. H. Daggett	
Ohio Northern Univ....	Feb. 9, '12	H. H. Robinson	F W. Evans, 302 E. Lincoln Avenue, Ada, Ohio.
Ohio State Univ........	Dec. 20, '02	R. G. Locket	D. A. Dickey, Ohio State University, Columbus, Ohio.
Oklahoma, Agricultural and Mech. Col...........	Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of....	Oct. 11, '12	Clifford O. Oster	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon Agr. Col.,......	Mar. 24, '08	Winfield Eckley	Fred E. Pinn, Oregon Agric. College, Corvallis, Ore.
Penn State College.....	Dec. 20, '02	J. E. Shreffler	Robert P. Meily, Pioneer House, State College, Pa.
Pittsburgh, Univ. of,....	Feb. 26, '14	G. W. Flaccus	Ralph C. Zindel, University of Pittsburgh, Pittsburgh, Pa.
Purdue Univ.,..........	Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Ind.
Rensselaer Poly. Inst...	Nov. 12, '09	W. J. Williams	S. N. Galvin, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst.,.	Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col.	Mar. 14, '13	Charles E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ..........	Dec. 13, '07	A. B. Stuart	H. J. Rathbun, Stanford University, Cal.
Syracuse Univ.,........	Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.........	Feb. 14, '08	J. M. Bryant	T. A. Cornell, Univ. of Texas, Austin, Tex.
Throop College of Technology...............	Oct. 14, 10	J. W. DuMond	K. W. Rich, Throop Poly, Institute, Pasadena, Cal.
Virginia Polytechnic Institute.................	Jan. 8, '15	V. Dixon	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of.......	Feb. 9, '12	W. S. Rodman	J. H. Moore, Dawsons Row, University, Va.
Wash. State Col. of....	Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Coll. of Wash. Pullman, Wash.
Washington Univ.......	Feb. 6, '04	Powell C. Roberts	Charles A. Lieber, Washington University, St. Louis, Mo.
Washington, Univ. of	Dec. 13, '12	E. C. Miller	Geo. S. Smith, Univ. of Washington, Seattle, Wash.
West Virginia Univ.	Nov. 13, '14	H. C. Schramm	C. L. Walker, West Virginia Univ., Morgantown, W. Va.
Worcester Poly, Inst....	Mar. 25, '04	R. M. Thackeray	C. C. Whipple, Worcester Polytechnic Institute, Worcester, Mass.
Yale University.........	Oct. 13, '11	P. G. Vonder Smith	S. R. Large, 343 Elm Street, New Haven, Conn.

Total 53.

American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXV — FEBRUARY, 1916 — Number 2

A. I. E. E. MIDWINTER CONVENTION

February 8-9, 1916

The fourth midwinter convention of the A. I. E. E. will be held in the Engineering Societies Building, 33 West 39th St., New York, February 8-9, 1916.

There will be four technical sessions, morning and afternoon, on Tuesday and Wednesday, and a dinner-dance at the Hotel Astor on Tuesday evening. The technical program is of a diversified character and includes a variety of subjects which will ensure wide interest. All of the papers are published in this issue of the PROCEEDINGS.

The Institute midwinter convention will be followed by a convention of the Illuminating Engineering Society, in the same building, on February 10-11, 1916, the dates of both conventions having been decided through cooperation of the two societies for convenience of members who desire to attend both conventions. Cordial invitations have been extended by both societies to all in attendance to participate in the technical sessions and social features of both conventions.

[A summary of the program for the Illuminating Engineering Society's convention is given in another column.]

Registration

The registration headquarters will be in the lobby of the Engineering Societies Building. In order to facilitate the handling of mail, telegrams and inquiries received for Institute members and others in attendance at the convention, it is desirable that members register themselves and their guests immediately upon their arrival. Upon registration each member and guest will receive a badge bearing his or her name, which for convenience in identification should be worn during the convention.

PROGRAM

Tuesday, February 8

10:00 A.M.

Address by President J. J. Carty.

1. *The A. I. E. E. and the Technical Committees*, by D. B. Rushmore.
2. *Municipally Operated Electric Utilities of Western Canada*, by A. G. Christie.

2:30 P.M.

Symposium on High-Voltage Measurements

3. *Crest Voltmeters*, by Clayton H. Sharp and E. W. Doyle.
4. *The Crest Voltmeter*, by L. W. Chubb.
5. *The Voltmeter Coil in Testing Transformers*, by A. B. Hendricks, Jr.
6. *Notes on the Measurement of High Voltage*, by William R. Work.

7:00 P.M.

Dinner-dance at Hotel Astor.

Wednesday, February 9

10:00 A.M.

Symposium on Electric Railway Operation

7. *Operation on the Norfolk and Western Railway*, by F. E. Wynne.

8. *Chattering Wheel Slip in Electric Motive Power*, by G. M. Eaton.
9. *The Liquid Rheostat in Locomotive Service*, by A. J. Hall.

2:30 P.M.

10. *Method of Determining the Correctness of Polyphase Wattmeter Connections*, by W. B. Kouwenhoven.
11. *The True Nature of Speech*, by John B. Flowers.

4:30 P.M.

Board of Directors Meeting at Institute Headquarters.

Dinner-Dance, Tuesday Evening, February 8th, 7:00 p.m.

In accordance with the custom established in previous years, of having a social function in connection with the convention for the benefit and entertainment of the members and guests, the Entertainment Committee has arranged for a subscription Dinner-Dance at the Hotel Astor, Broadway and 44th Street, New York, on Tuesday evening, February 8th, at seven o'clock, in which all members and their guests are cordially invited to participate. The arrangements provide for eight persons at a table. Dancing will follow immediately after the dinner. The subscription price is $5.00 per person. Applications for reservations should be made promptly to the Entertainment Committee at Institute headquarters, and should be accompanied by the names of guests.

INSPECTION TRIPS

The following companies have courteously offered to open their plants for inspection by members or guests either individually or in groups, between the hours named below on each day of the convention. The A. I. E. E. convention badge will be accepted as sufficient identification.

New York Edison Company,
10:00 A.M. - 4:00 P.M.

Waterside Power Stations, 38th-40th Streets and First Avenue.

Substation, 115-117 West 39th Street.

United Electric Light & Power Co.,
2:00 P.M. - 5:00 P.M.

Power Station, 201st St. and Harlem River.

Substation, Tremont Ave. and Watson Lane.

During the past year two 20,000-kv-a. turbo-generators have been installed in the 201st Street Station, and this power is transmitted to the West Farms Substation and distributed to the N. Y. N. H. & H. R. R.

Interborough Rapid Transit Company,
2:00 P.M. - 5:00 P.M.

Power Station, 59th Street and North River.

Power Station, 74th Street and East River.

New York Telephone Company,
2:00 P.M. - 5:00 P.M.

Murray Hill Exchange, 221 East 37th Street.

Electrical Testing Laboratories,
2:00 P.M. - 5:00 P.M.

80th Street and East End Avenue.

ILLUMINATING ENGINEERING SOCIETY CONVENTION

The midwinter convention of the Illuminating Engineering Society will be held in the Engineering Societies Building, New York, on Thursday and Friday, February 10 and 11, 1916, following the A. I. E. E. midwinter convention. The list of papers to be presented shows a wide range of subjects, comprising a review and record of what has been accomplished in the art and science of illuminating engineering, and it is hoped that the discussion will bring forth plans for the future advance of the art.

The convention will be formally opened at 10 o'clock Thursday morning, in the auditorium, with an address of welcome by Mayor Mitchel. Mr. Arthur Williams will preside at this session.

This convention, which celebrates the tenth anniversary of the Illuminating Engineering Society, will be sig-

nalized by the conferring of honorary membership in the society on Mr. Thomas A. Edison. The presentation of honorary membership will be made at a banquet at the Biltmore Hotel on Thursday evening, February 10, the eve of Mr. Edison's birthday. Dr. Charles P. Steinmetz will act as toastmaster at this banquet and among the speakers will be Governor Whitman and Mayor Mitchel. The presentation will be made by Mr. John W. Lieb. The dinner will begin at 7:30 and it is hoped that all members and their friends will arrange to be present at this time. Subscription to the banquet will be $5.00, and ladies visiting the convention from out of town will be guests.

An interesting feature will be a popular lecture given on Friday afternoon by Mr. W. D'Arcy Ryan, the designer of the lighting for the Panama-Pacific International Exposition. This will be illustrated by colored transparencies 24 by 36 feet, which will convey more completely than otherwise possible to those who have not visited the Exposition the wonderful lighting effects produced with color.

All members of the A. I. E. E. are invited to participate in the convention activities of the Illuminating Engineering Society.

1916 YEAR BOOK

The Institute Year Book for 1916 has been published and may be obtained free of charge by any member upon application to the Secretary, 33 West 39th Street, New York, by mail or otherwise.

The book, which is published primarily for distribution to prospective members in connection with the work of the Membership Committee, contains the constitution, by-laws, lists of officers and committees, alphabetical and geographical catalogues of the membership, and considerable other general information relating to the activities of the Institute.

DIVERSIFIED ACTIVITIES OF THE INSTITUTE

By President Carty*

The activities of the Institute are manifold and cover all branches of electrical engineering, which are represented by committees composed of the leading engineers in their respective departments.

In the increasing complexities of modern development, both civil and military, the Institute has come to be recognized by the state and national authorities as the representative body of electrical engineers in this country, and it is called upon from time to time to take action in many ways relating to matters of great public importance in different states in the Union and by the national government itself. Recently, upon the request of the Secretary of the Navy, the Institute designated two of its members for appointment upon the Naval Consulting Board, and upon another occasion it appointed a committee to cooperate with the War Department in matters pertaining to the national defense.

So important has the work of the Institute become that it is now recognized that every young man seeking for a career in electrical engineering should qualify himself, as soon as practicable, to become enrolled in its membership, and for the encouragement of such young men Branches have been established in our universities, so that students may be enrolled during the time of their college studies and subsequently become members. The usefulness of these branches has been so widely recognized that from less than six in 1902 they have grown to more than fifty at the close of 1915.

To extend still further the usefulness of the Institute and to emphasize thoroughly its national character, Sections were started in the principal cities of the country. The work of these Sections became so important that they

*Reprinted from the *Electrical World*, January 1, 1916.

have now been established in all parts of the United States, increasing from five in 1902 to more than thirty in 1915.

The American Institute of Electrical Engineers stands for the highest achievement in electrical engineering and for the most distinguished attainments among its members.

From the art of electrical engineering as it stands in the world today take away the contributions of the members of the American Institute of Electrical Engineers, and that which would be left would make a sorry showing by comparison.

The art of telephony would disappear, and all of those wonderfully co-ordinated activities of both peace and war depending upon that means of communication would instantly be paralyzed.

In electric lighting and energy distribution for all purposes the contributions of our members have been so fundamental, so important and so numerous that it is difficult to picture the chaos which would result if, by some magic, their wonderful work could be undone.

By its papers and meetings and discussions, by the spread of knowledge through its published PROCEEDINGS and TRANSACTIONS, and, above all, by the high ideals of its members and by the unsurpassed character of their achievements, the Institute has taken a foremost place among the forces making for the welfare and unity of our country.

MEMBERSHIP COMMITTEE

The following figures, showing the number of applications for admission to the Institute received during the three months ending December 31, 1915, will, it is thought, be of interest.

Sections	Applications Received October 1, 1915 to December 31, 1915.	Per Cent of Present Section Membership
Atlanta	1	2
Baltimore	0	0
Boston	8	2
Chicago	13	3
Cleveland	6	4
Denver	12	32
Detroit-Ann Arbor	2	1.5
Fort Wayne	0	0
Indianapolis-Lafayette	2	4
Ithaca	2	3.5
Los Angeles	3	2
Lynn	2	2
Madison	0	0
Milwaukee	4	3
Minnesota	1	1
Panama	1	1.5
Philadelphia	13	4
Pittsburgh	11	3
Pittsfield	0	0
Portland	1	1
Rochester	2	3.5
St. Louis	9	8
San Francisco	5	2
Schenectady	13	4
Seattle	3	4
Spokane	1	2
Toledo	2	9
Toronto	2	1.5
Urbana	2	8
Vancouver	1	2
Washington, D. C.	3	3.5
	125	

Total number of members located in Section territory 4062

Percentage for Section territory 3%

Received from applicants outside Section territory 120

Total number members outside Section territory 3924

Percentage for outside territory 3%

Totals 245 7986

LIBRARY REPORT FOR 1915

The Library Board of the United Engineering Society has published its annual report for 1915, the first year during which the library of the American Institute of Electrical Engineers has been administered jointly with the libraries of the American Institute of Mining Engineers, the American Society of Mechanical Engineers, and the United Engineering Society, under the agreement which provided that "The four libraries of the said societies shall be controlled and administered as one joint library by the Library Board of the United Engineering Society in accordance with the by-laws of that so-

ciety." This agreement, after being ratified by the governing bodies of the founder societies, took effect as of January 1, 1915.

The Library Board's report includes many interesting statistics of the accessions to the library, its utilization, and its finances, which can be only briefly summarized here.

The number of visitors to the library during the year was 12,820, or an average of 41 per day. Of these 2,218 made use of the library during the evening after 6 p. m.

An important part of the library's work is that carried on by the Library Service Bureau, which furnishes reference lists, undertakes patent searches, makes translations, and prepares typewritten or photostat copies, for engineers desiring this service. This work has been carried on for several years, but was not formally organized until 1915. During the year the Library Service Bureau fulfilled 679 requests for service, classified as follows: reference lists, 307; translations, 71; photostat prints, 301. A charge is made for this service, sufficient to cover the cost of the work.

In July, 1915, the library met an important need by publishing a Catalogue of Technical Periodicals to be found in seven libraries in the City of New York and vicinity, namely, Columbia University Library, the Library of the Chemists' Club, the Library of the American Society of Civil Engineers, the Library of the Engineering Societies, the New York Public Library, the Library of Stevens Institute of Technology, and the Public Library of Plainfield, New Jersey. The book is intended to contain a complete record of foreign and domestic periodicals and publications of technical and learned societies, especially as to all changes of title, consolidations, publications of indexes and dates of suspension or cessation of publication.

During the year the collections of the library have been increased by the following accessions: volumes, 2,535; pamphlets, 621; maps, 58; total, 3,214.

During the year 3,656 books, pamphlets and maps have been catalogued, and 1,266 volumes of periodicals have been added to the library file.

The Library of the Engineering Societies constitutes the greatest and potentially the most useful engineering library in the world, in consequence of the unusually large number of engineering and scientific periodicals which it receives and binds. On January 1, 1915, it was receiving currently 1,020 periodicals bearing different titles, from 29 different countries.

The report includes a complete list of the donors of books and pamphlets to the library during the year.

Members interested in further details may obtain copies of the report by addressing the Secretary of the Institute.

LIGHT OF HEFNER LAMP AS AFFECTED BY ATMOSPHERIC CONDITIONS

Dr. Clayton H. Sharp, Secretary of the United States National Committee of the International Commission on Illumination, announces that he has received from the National Illumination Committee of Great Britain reprints of a translation of a paper by Dr. Ott on "The Dependence of the Light of the Hefner Lamp on Atmospheric Conditions." These copies are available for distribution to such members of the Institute as desire to have them. Applications should be addressed to Dr. Sharp at 80th Street and East End Avenue, New York, N. Y.

SECOND PAN-AMERICAN SCIENTIFIC CONGRESS

As announced in the December, 1915, PROCEEDINGS, the Second Pan-American Scientific Congress was held in Washington, D. C., December 27, 1915, to January 8, 1916, and was attended by delegates from the nations of North and South America. The first Pan-

American Scientific Congress was held in Santiago, Chile, December 25, 1908, to January 5, 1909.

The American Institute of Electrical Engineers participated in the preparation of the preliminary program covering the Engineering Section, through the following representatives who were appointed as members of the Engineering Committee of the Congress: Messrs. John H. Finney, F. L. Hutchinson, Percy H. Thomas and John B. Whitehead.

Under Section V—Engineering, Subsection 3—Electrical Engineering had as chairman, Professor John B. Whitehead, and alternate chairman, Mr. John H. Finney. The Institute was officially represented throughout the Congress by Mr. Finney, who was appointed alternate to Mr. Gano Dunn, and by Mr. William McClellan.

Several important papers were prepared by South American authors for the Electrical Engineering Section, and among the notable ones were:

" Electric Current and Flow," by Dr. Bautute Layntry, of Uruguay.

" Exact Calculation of Electric Transmission Lines," by Dr. Arturo E. Salazar, of Chile, and presented by the author in person.

" Radiotelegraphy in Uruguay," by Dr. Bernado Kayel of Uruguay.

" Wireless Telegraph Service and Conventions," by Emilio E. Dagassan, of the Argentine Navy.

" Water Powers in Brazil," by Dr. Luiz Betim Paes-Leme, of Brazil, presented by the author in person.

In addition to Subsection 3—Electrical Engineering, some papers of interest to electrical engineers were presented under the headings of Standards, and Irrigation, including, in addition to those already mentioned, the following:

" Electrochemical Industries," by Prof. G. A. Roush, Lehigh University, South Bethlehem, Pa.

" Industrial Applications of Electricity," by Philip Torchio, New York.

" Present Status of Water Power Development," by H. W. Buck, New York.

" Hydroelectric Utilization at Niagara and Elsewhere," by Maurice Deutsch, New York.

" Use of Irrigation Waters as Sources of Power," by George G. Anderson, Los Angeles, Cal.

" Acceptance Tests of Electrical Apparatus," by Dr. Clayton H. Sharp, Technical Director, New York Electrical Testing Laboratories.

" Work of the United States National Bureau of Standards," by S. W. Stratton, Director, U. S. Bureau of Standards, Washington, D. C.

" Electric Power Transmission and Distribution Systems," by Percy H. Thomas, New York.

" Aluminum Conductors for Electric Transmission Lines," by Theodore Varney, Pittsburgh, Pa.

" Underground Cables," by H. W. Fisher, Perth Amboy, N. J.

" Electrical Codes and Standards," by Edward B. Rosa, U. S. National Bureau of Standards, Washington, D.C.

" Recent Telegraph and Telephone Development," by F. B. Jewett, New York.

" Electrification of Transportation Lines," by N. W. Storer, East Pittsburgh, Pa.

" Physical Aspects of Radiotelegraphy," by John N. Hogan, Jr., Brooklyn, N. Y.

Many papers were presented on the subject of " Laws and Regulations Regarding the Use of Water for All Purposes," and also on " Engineering Nomenclature," both of these topics having been referred to the Second Congress by its predecessor. Several papers were also presented on " Engineering Education."

In conclusion, a very large amount of scientific knowledge was presented and the discussions were interesting and clarifying. While the technical sessions were valuable, there was even more value to Pan-America in the fellowship, good feeling and understand-

ing evidenced throughout the entire Congress and emphasized by nearly every speaker and delegate.

A. I. E. E. MEETING IN NEW YORK JANUARY 14, 1916

The 317th meeting of the American Institute of Electrical Engineers was held in the Engineering Societies Building, New York, on Friday, January 14, 1916.

President John J. Carty called the meeting to order at 8:20 p. m., introducing Past-President Dr. Charles P. Steinmetz, who presented his paper entitled *Outline of Theory of Impulse Currents.* The paper was discussed by Dr. Michael I. Pupin, Prof. Harold Pender, Messrs. David B. Rushmore, Hans Lippelt, and Dr. Steinmetz.

DIRECTORS' MEETING NEW YORK, JANUARY 14, 1916

The Board of Directors of the Institute held its regular monthly meeting in New York on Friday, January 14, at 3:30 p. m.

There were present: President John J. Carty, New York; Past-President C. O. Mailloux, New York; Vice-Presidents N. W. Storer, Pittsburgh, Pa., Farley Osgood, Newark, N. J., C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William McClellan, New York; Managers H. A. Lardner, San Francisco, Cal., B. A. Behrend, Boston, Mass., P. Junkersfeld, Chicago, Ill., L. T. Robinson, Schenectady, N. Y., Frederick Bedell, Ithaca, N. Y., Bancroft Gherardi, New York, A. S. McAllister, New York, John H. Finney, Washington, D. C., C. E. Skinner, Pittsburgh, Pa., John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa.; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $7,272.45 was ratified.

Upon the recommendation of the Meetings and Papers Committee it was voted to hold the 1916 Annual Convention of the A. I. E. E. in Cleveland, Ohio, during the last week in June, and the President was authorized to appoint a Convention Committee to cooperate with the Meetings and Papers Committee in making the arrangements and preparing the program.

The report of the Board of Examiners of its meeting held on January 6 was read, and its actions taken upon the applications considered at that meeting were approved.

Upon the recommendation of the Board of Examiners, one Member was transferred to the grade of Fellow and three Associates were transferred to the grade of Member, three applicants were elected to the grade of Member, and 104 to the grade of Associate, and 71 students were ordered enrolled, in accordance with the lists published in this issue of the PROCEEDINGS.

Upon the petition of Dr. Erich Hausmann, and the approval of the Sections Committee, authority was granted for the organization of a Branch at the Brooklyn Polytechnic Institute.

The Constitutional Revision Committee submitted its report recommending certain amendments to the Constitution, which were approved by the Board of Directors, and the committee was authorized to prepare an explanatory circular letter and the ballots, and submit the amendments to the membership for a vote as required by the Constitution.

A considerable amount of other business was transacted, reference to which will be found in this and future issues of the PROCEEDINGS.

PAST SECTION MEETINGS

Baltimore.—January 14, 1916, Electrical Engineering Laboratory, Johns Hopkins University. Paper: "Electron Emission from Heated Metals in Its Relation to Electrical Engineering," by Saul Dushman. Paper illustrated

by lantern slides and experimental demonstrations. Attendance 60.

Boston.—November 18, 1915, Providence, R. I. Inspection trip to plants of Gorham Manufacturing Company, General Fire Extinguisher Company, and Brown and Sharpe Company. Inspection of engineering laboratories at Brown University, followed by dinner at Narragansett Hotel. After dinner addresses by the Secretary to the Mayor Joseph H. Gainer, Dr. W. H. P. Faunce, Prof. Charles E. Munroe, Mr. Morris L. Cooke and Mr. M. C. Rorty. Mr. Rorty's address was illustrated with motion pictures of telephone work and was followed by talk to San Francisco, each person in the room being provided with a receiver. Joint meeting of Boston Section A. S. M. E. and Providence Society of Mechanical Engineers, to which Boston Section A. I. E. E. was invited.

December 7, 1915, Engineers Club. Addresses on "Fire Hazard and the Electrical Engineer," by Messrs. N. H. Daniels, Ralph W. Sweetland, G. S. Lawler and John A. O'Keefe. Attendance 110.

January 14, 1916, Franklin Union. Paper: "The Oscillograph," by H. G. Crane and C. L. Dawes. Demonstration of speech over long-distance telephone to San Francisco. President J. J. Carty spoke a few words to the Boston Section over the line from New York. During these demonstrations the voice wave was thrown on the screen through the oscillograph. Attendance 650.

Chicago.—December 29, 1915. Paper: "Naval Preparedness and the Civilian Engineers," by Frank J. Sprague. Attendance 170.

Cleveland.—December 20, 1916, Hollenden Hotel. Paper: "Civic Duties for Engineers," by S. E. Doane. Address on "The Development and Installation of the First Commercial Arc Lighting System," by Charles F. Brush. Joint meeting with the Cleveland Advertising Club, the Electrical League and the Cleveland Engineering Society. Attendance 275.

Indianapolis-Lafayette.— December 17, 1915, Indianapolis. Address on "Preparedness—A Study of the Future Probabilities of the Telephone in Indianapolis," by J. W. Stickney. Attendance 40.

Los Angeles.—December 21, 1915, Chamber of Commerce Building. Paper: "Dispatching," by T. J. Royer and F. H. Coble. Attendance 29.

Lynn.—December 15, 1915, General Electric Works, West Lynn. Address by Mr. H. E. Duncan on "The Effect of Legislation on Our Industries." Attendance 175.

January 5, 1916, General Electric Works, West Lynn. Address by Prof. Elihu Thomson on "Optical Instruments." Prof. Thomson exhibited a large assortment of objectives, condensers, microscopes and samples of optical glass.

Milwaukee.—December 15, 1915, Republican House. Address by Mr. W. B. Hanlon on "The Relationship that Should Exist between the Engineers' Society and the Administration of Municipal Affairs." Attendance 60.

Pittsburgh.—December 4, 1915, Fort Pitt Hotel. Annual banquet of Pittsburgh Section. Addresses by President J. J. Carty and Messrs J. J. Jackson and W. B. Clarkson, followed by entertainment. Attendance 312.

January 11, 1916, Carnegie Institute of Technology. Paper: "Recent Progress in Radiotelegraphy," by Arthur F. Van Dych. Demonstration of recently installed radio station at Carnegie Institute of Technology. Attendance 192.

Pittsfield.—October 28, 1915, Hotel Wendell. Paper: "Electricity Supply in Large Cities," by Philip Torchio. Paper was illustrated with lantern slides and charts. Attendance 95.

Schenectady.—December 21, 1915, Edison Club Hall. Lecture by Dr. Charles P. Steinmetz on "The Different Classes of Conduction—Metallic, Electrolytic, Pyroelectric, Insulation, Gas, Vapor and Electronic—and How They are Inter-related." Attendance 352.

January 4, 1916, Edison Club Hall. Address by Prof. W. S. Franklin on "The Second Law of Thermodynamics." Attendance 300.

Seattle Section.—December 21, 1915, Chamber of Commerce. Paper: "Electric Heating, Its Present Status and Future Possibilities," by J. D. Ross. Attendance 21.

Toledo.—January 12, 1916, Toledo Commerce Club. Paper: "Underground Transmission Cables," by W. E. Richards. Attendance 40.

Urbana.—December 17, 1915, Physics Lecture Room. Paper: "The Electrification Problem in Chicago," by W. F. M. Goss. Attendance 165.

Vancouver.—December 16, 1915, Dominion Telegraph and Wireless Institute Rooms. Address by Mr. A. E. Makin on "Radiotelegraphy." Attendance 43.

PAST BRANCH MEETINGS

Armour Institute. January 4, 1916, Chapin Hall. Paper: "Automatically Controlled Substations." Attendance 12.

University of California.—December 1, 1915, A. E. M. E. Room. Paper: "Phase Compensation," presented by Mr. McFarland. Attendance 18.

Carnegie Institute of Technology.—December 15, 1915, Machinery Hall. Address by Mr. Alan S. Young on "Electrical Measuring Instruments." Attendance 72.

Clarkson College.—January 5, 1916. Election of officers as follows—chairman. W. A. Dart; secretary, C. J. Dresser. Papers: (1) "The Diesel Engine"; (2) "Axle Shafts for Motor Trucks." Attendance 37.

Clemson Agricultural College.—October 4, 1915. Reviews of current technical magazines. Paper: "The Speaking Arc," by Mr. Lester. Election of officers as follows—chairman, D. H. Banks, secretary, W. H. Neil; treasurer, D. F. Folger.

November 15, 1915. Debate—"Resolved, that Electrical Transportation for Long-Distance Traffic Should Supersede Steam Transportation on American Railroads."

December 13, 1915. Paper: "Hydraulics," by Prof. Sweeney.

Colorado State Agricultural College. January 10, 1916, Mechanical Building. Address by Mr. N. L. Chatfield on "The Sugar Industry." Joint meeting with local branch of A. S. M. E. Attendance 8.

Highland Park College.—December 29, 1915, Electrical Laboratory. Address by Mr. L. E. Engle on "Refrigeration." Attendance 64.

Kansas State Agricultural College.—December 22, 1915. Illustrated lecture on "The Keokuk Development of the Mississippi River Power Company," by R. S. Baker. Address by Mr. J. S. Hagan on "Why Students Should Join the A. I. E. E." Attendance 37.

University of Kansas.—January 19, 1916. Illustrated address by Mr. A. R. Willson on "The Power Supply System for the Street Railway and Lighting Companies of Kansas City, Mo."

University of Maine.—January 12, 1916, Hannibal Hamlin Hall. Paper: "History of Telephone Development." Illustrated lecture by Prof. A. T. Childs on "Prominent American Engineers." Attendance 44.

Ohio State University.—January 14, 1916, Auditorium, Robinson Laboratory. Address by Mr. E. W. Penton on "Vehicle Batteries." Attendance 32.

Pennsylvania State College.—January 12, 1916, 200 Engineering Club. Illustrated lecture by Dean R. L. Sackett on "Hydroelectric Power Development." Attendance 52.

Purdue.—January 7, 1916. Lecture by Dr. W. S. Franklin on "Mechanical Analogies of Electromagnetic Phenomena." Attendance 204.

Rhode Island State College.—January 5, 1916. Paper: "Electrification of the Panama Canal," illustrated by lantern slides. Attendance 62.

Syracuse University.—December 9, 1915. Paper: "Salesmanship," by Mr. Schrantz. Attendance 30.

January 6, 1916. Paper: " Lightning Arresters," by Geo. A. Laurer. Attendance 14.

January 13, 1915. Paper: "X-Rays," by L. W. Gay. Attendance 14.

University of Texas.—December 3, 1915. Address by Prof. J. M. Bryant on " Rates for Public Utility Service." Attendance 24.

Washington State College.—December 10, 1915. Illustrated lecture by Mr. E. F. Keyes on " The Telephone System." Attendance 35.

January 7, 1916. Illustrated lecture on " Transformers " by Prof. H. V. Carpenter.

University of Washington.—January 4, 1916, Forestry Building. Papers: (1) " Induction Water Heaters "; (2) " Duties of a Station Operator." Attendance 17.

Worcester Polytechnic Institute.—December 17, 1915, Electrical Engineering Lecture Hall. Paper: " Electrification of the Grand Central Terminal," by Edwin B. Katte. Attendance 80.

PERSONAL

Mr. A. F. Hovey has been made manager of the construction department of the Standard Underground Cable Company, at Pittsburgh, Pa.

Mr. Tracy D. Waring has been made assistant manager of the lead cable works and the rubber wire factory at the Perth Amboy, N. J., plant of the Standard Underground Cable Company.

Mr. Charles W. Davis, formerly manager of the Standard Underground Cable Company's Central sales department, general superintendent of construction and manager of the accessories department, has been appointed vice-president and general sales manager of the company.

Mr. H. W. Fisher, chief electrical engineer of the Standard Underground Cable Company, has been appointed to hold, in addition, the position of manager of the lead cable works and rubber wire and cable factories, under the assistant general manager and president; he is also made an officer of the company by virtue of his appointment as assistant secretary, but will be located at Perth Amboy, N. J., as heretofore.

Mr. Harry R. Westcott has opened an office in the Chamber of Commerce Building, New Haven, Conn., for a general practise in industrial, electrical and power station engineering. Mr. Westcott's experience has included twelve years of designing, constructing and operating work. He has recently been superintendent of construction for the United Illuminating Company of New Haven, making extensive improvements in its plants, and is still retained by that company as its consulting engineer.

Mr. Paul M. Lincoln, Past-President of the Institute, on January 1 became associated with the sales organization of the Westinghouse Electric and Manufacturing Company with the title of Commercial Engineer. Mr. Lincoln's original connection with the Westinghouse company began in 1892. He is well known as a writer on technical subjects and has also been identified with educational work for some time, filling the chair of professor of electrical engineering of the University of Pittsburgh. He was graduated from Ohio State University in 1892.

Mr. Waldemar R. Kremer has been appointed general sales manager of the Vilter Manufacturing Company of Milwaukee, Wis., to succeed the late Fred Ulrich. Mr. Kremer has been connected with the company for nearly ten years as consulting electrical and mechanical engineer in the sales department. He is a graduate of the electrical and mechanical engineering courses of the Royal Polytechnic Institute, Munich, Germany, and the Massachusetts

Institute of Technology. In his new capacity Mr. Kremer will have general charge of sales and supervision of branch offices and agencies in this and foreign countries.

RECOMMENDED FOR TRANSFER, JANUARY 6, 1916

The Board of Examiners, at its regular monthly meeting on January 6, 1916, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To the Grade of Member

Carroll, John Gustave, Electrical Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Kerr, William C., Construction Engineer, Philadelphia Rapid Transit Co., Philadelphia, Pa.

TRANSFERRED TO THE GRADE OF FELLOW JANUARY 14, 1916

The following Member of the Institute was transferred to the grade of Fellow at the meeting of the Board of Directors on January 14, 1916.

Ellicott, Edward B., Chief Electrical Engineer, Sanitary District of Chicago, Chicago, Ill.

TRANSFERRED TO THE GRADE OF MEMBER JANUARY 14, 1916

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on January 14, 1916.

Christians, George W., Construction Engineer, Chattanooga & Tennessee River Power Co., Guild, Tenn.

Kean, A. J. A., Assistant General Manager, Guanajuato Power & Electric Co., Guanajuato, Mexico.

Rose, Clarence E., Vice-President & Manager, Arkansas Cold Storage Co., Little Rock, Ark.

MEMBERS ELECTED JANUARY 14, 1916

Arnold, Harold DeForest, Telephone Engineer, Western Electric Co., 463 West St., New York, N. Y.

Hull, John Irving, Electrical Engineer, General Electric Co.; res., 938 Albany St., Schenectady, N. Y.

Knight, Abner Richard, Associate in Electrical Engineering, University of Illinois, Urbana, Ill.

ASSOCIATES ELECTED JANUARY 14, 1916

*Achard, Francis H., Tester, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

*Allen, Richard Cleveland, Draftsman, Union Electric Light & Power Co., St. Louis; res., 555 N. Clay Ave., Kirkwood, Mo.

*Anderson, Earl G., Cadet Engineer, Denver Gas & Electric Co.; res., 1144 Pearl St., Denver, Colo.

Anderson, Pierson Anthony, Engineering Inspector, Western Electric Co., Worcester, Mass.

*Arms, Louis Pliny, Assistant Engineer, Swift & Co., South Omaha; res., 4522 So. 25th St., Omaha, Nebr.

*Avis, Samuel Lee, Construction Engineer, Jamestown, N. D.

*Baker, Paul William, Engineer, Wagner Electric Mfg. Co.; res., 1213 Bayard Ave., St. Louis, Mo.

Betts, Charles R., Operator, 303 Hamilton Ave., Palo Alto, Cal.; res., Estacada, Oregon.

*Bishop, Albert Bentley, Inventory and Appraisal of Electrical Property, D. C. & Wm. B. Jackson; res., 1943 Norris St., Philadelphia, Pa.

*Bliem, Howard M., Assistant, Engineering Dept., San Antonio Gas & Electric Co.; res., 235 W. Mistletoe Ave., San Antonio, Tex.

*Brown, Loren Elden, Graduate Apprentice, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.; res., Delphos, Kans.

BULLOCK, WILLIAM HARRISON, Representative, Westinghouse Elec. & Mfg. Co., 1052 Gas and Electric Bldg., Denver, Colo.

CANNON, JOSEPH HENDERSON, Associate Professor of Electrical Engineering, A. & M. College of Texas, College Station, Texas.

*CARSON, DALE BRADFORD, H. L. Doherty & Co., 60 Wall St., New York, N. Y.

CRAIG, GEORGE C., Student in Industrial Electricity, Franklin Union; res., 30 Minden St., Roxbury, Mass.

DAVIS, O'DONEL, Electrical Engineer, Christchurch City Council; res., 13 Poynder Ave., Fendalton, Christchurch, N. Z.

DENNISS, GEORGE M., Chief Operator, Adirondack Electric Power Corp.; res., 1114 Seymour Ave., Utica, N. Y.

*DRAPER, F. E., Safety Inspector and Safety Engineer, State of California, Los Angeles; res., 217 East C St., Ontario, Cal.

*EARDLEY-WILMOT, TREVOR, Estimating Engineer, Installation Dept., Northern Electric Co. Ltd.; res., 2 King George Apt., Oldfield Ave., Montreal, Que.

EKSERGIAN, RUPEN, Research Assistant, Massachusetts Institute of Technology, 203 Pierce Hall, Cambridge, Mass.

*EVANS, PORTER H., Teaching Assistant in Electrical Engineering, University of Michigan; res., 616 East Huron St., Ann Arbor, Mich.

*FARMER, TROI O., Assistant, Electrical Engineering Dept., Ohio State University; res., 50 W. 8th Ave., Columbus, Ohio.

FOOTE, WILLIAM WINTER, General Foreman, Cia Riegos y Fuerzos del Ebro, Barcelona, Spain.

FREEMAN, LOUIS GEORGE, Assistant Electrical Engineer, U. S. Geological Survey, Washington, D. C.

*GAMBRILL, WILSON N., Student Engineer, General Electric Co.; res., 46 Mall St., W. Lynn, Mass.

*GIBBS, CLARENCE DENTON, Student Engineer, General Electric Co.; res., 712 Union St.,. Schenectady, N. Y.

GILLETTE, EDMOND STEPHEN, Electrical Engineer, Aurora, Elgin and Chicago R.R. Co.; res., 345 Galena Blvd., Aurora, Ill.

*GODSHO, ALBERT PAUL, Student Engineer, Bell Telephone Co. of Pa., res., 1502 N. Robinson St., Philadelphia, Pa.

*GORTON, LEO H., Resident Engineer, Benham Engineering Co., 1300 Colcord Bldg., Oklahoma City, Okla.

*GOULD, EDWARD EARLY, Student, Highland Park College; res., 3316 First St., Des Moines, Iowa.

GUEST, WALTER SCOTT, Lecturer, University of Toronto; res., 30 McMaster Ave., Toronto, Ontario.

*HAPFOLD, HAROLD HENRY, Electrical Draftsman, Wagner Electric Mfg. Co.; res., 5088 Cabanne Ave., St. Louis, Mo.

*HART, ROY HERBERT, Telephone Engineering, Western Electric Co., 463 West St., New York, N. Y.

*HEDGE, LAFAYETTE BOYD, Chief Electrician, Ely Light and Power Co., East Ely, Nevada.

*HERRMANN, RAYMOND RUSSEL, Engineering Assistant, Municipal Testing Laboratories, St. Paul, Minn.

HORI, MOTOWO, Electrical Engineer, Mitsubishi Dockyard & Engine Works, Kobe, Japan.

*HORRELL, CHARLES RUSH, Sales Engineer, Electric Appliance Co., 701 W. Jackson Blvd., Chicago, Ill.

*HUBBELL, JAMES DAVIS, JR., Telephone Engineer, Western Electric Co.; res., 521 West 112th St., New York, N. Y.

*HUGHES, EDGAR LUDWIG, Electrician, Northern California Power Co. Cons., Red Bluff, Cal.

*HUNTER, DAVID HARRISON, General Engineering Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 516 Holmes St., Wilkinsburg, Pa.

JENKINS, DAVID RHYS, Asst. Professor of Electrical Engineering, University of Colorado; res., 1327 17th St., Boulder, Colo.

*JOHNS, HYLAND RIGHTER, Assistant Engineer, U. S. Patent Office; res., 1450 Harvard St., Washington, D. C.

*JONES, MARTIN LUTHER, Light & Power Solicitor, City Light; res., 3223 41st St. S. W., Seattle, Wash.

*KAUFMAN, LEWIS BERNHARD, Junior Railway Engineer, Public Service Commission, 1st Dist.; res., 439 Manhattan Ave., New York, N. Y.

*KAY, WILLIAM DE YOUNG, Power Engineer, Edison Illuminating Co. of Brooklyn; res., 1 W. 94th St., New York, N. Y.

*KENNEDY, VERNE CORNELIUS, Assistant, Electrical Engineering Laboratory, Massachusetts Institute of Technology, Boston, Mass.

*KING, CHARLES FISHER, JR., Electrical Dept., Pennsylvania Railroad Co., Altoona, Pa.

*KROLL, CORNELIUS, Operating Dept., W. S. Barstow & Co.; res., 318 E. 84th St., New York, N. Y.

KYLIE, HARRY R., Supt., Telephone Construction, Forest Service, Denver, Colo.

*LICKEY, HARRY FOSTER, Instructor of Physics and Mathematics, Hailey High School, Hailey, Idaho.

*LORD, LESTER, Asst. System Operator, Public Service Co. of Northern Illinois; res., 1564 Florence Ave., Evanston, Ill.

LYNETT, JAMES D., Inspector of Electrical Conductors, Bureau of Gas and Electricity, City of New York, Borough Hall, St. George, N. Y.

LUCAS, CHARLES CRAIGHILL, JR., Assistant, Experimental Dept., Burke Electric Co.; res., 252 W. 10th St., Erie, Pa.

MACINDOE, GEORGE, Demonstrator in Electrical Engineering, School of Engineering, Canterbury College, Christchurch, New Zealand.

*MANBECK, PARK DANIEL, Nungesser Carbon and Battery Co., Cleveland; res., 92 Brightwood St., East Cleveland, Ohio.

*MCCURDY, RALPH GORDON, Engineer, Joint Committee on Inductive Interference, Railroad Commission of California, 833 Market St., San Francisco, Cal.

MCDOWELL, THEODORE APPEL, Commercial Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

MCGREGOR, JAMES J., Electro-plater, 162 Broadway, Cambridge; res., 19 Albion St., Somerville, Mass.

MESSENGER, ARTHUR RAY, Town Clerk and Manager of Public Utilities, Fonda, Iowa.

MOORE, HERBERT S., Purchasing Agent, Fort Dodge, Des Moines & Southern R. R., Boone, Ia.

*MULLIN, JAMES WALTER, Assistant Receiving Engineer, Marconi Station, Louisburg, Nova Scotia.

NINOMIYA, YUZURU, Electrical Engineer, Shibaura Engineering Works, Tokyo, Japan.

NORRIS, ALBERT, Lieutenant, U. S. Navy, In Charge of Electrical and Mechanical Testing Laboratory, Navy Yard, Brooklyn, N. Y.

*OAKES, MALCOLM CHRISTIE, Assistant in Electrical Engineering, University of Oklahoma; res., 530 West Symmes St., Norman, Okla.

*OEHLER, WILLIS A., Draftsman, Crocker Wheeler Co., Ampere; res., 168 N. 18th St., E. Orange, N. J.

*OGDEN, PHILIP L., Service Engineer, Westinghouse Electric & Mfg. Co.; res., 620 E. 35th St., Chicago, Ill.

*OPPENHEIMER, LEO ADOLPH, Engineering Dept., San Antonio Gas & Electric Co.; res., 318 Goliad St., San Antonio, Tex.

*OVER, RAYMOND W., Testman, Central District Telephone Co., Pittsburgh; res., Haysville, Pa.

*PAINE, CHARLES KENNETH, Sales Engineer, The Korsmeyer Co.; res., 1448 Washington St., Lincoln, Nebr.

PARK, STANLEY WILSON, Electrician, Britannia Beach, B. C., Canada.

*Parsons, Morgan, In charge of Material on Transmission line construction, Stone & Webster Engg. Corp., Boston, Mass.; res., 4037 Spruce St., Philadelphia, Pa.

*Paterson, James Bruce, Field Engineer, Central District Telephone Co.; res., 600 E. Pittsburgh St., Greensburg, Pa.

*Post, Frank Burdette, Draughtsman, Elec. Engg. Dept., Puget Sound Traction, Light & Power Co.; res., 2121 Queen Anne Ave., Seattle, Wash.

Radamaker, M., Electrical Engineer, Le Bron Electric Works; res., 2021 Lincoln Ave., Omaha, Neb.

*Rankin, Ralph Smedberg, Engineering Dept., American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

*Restofski, Harry, Power Dept., West Penn Railways Co., Connellsville, Pa.

Richards, Carl William, Electrical Valuation Work, Sanitary District of Chicago; res.,6223 Blackstone Ave.. Chicago, Ill.

*Richmond, Alfred Leroy, Chief Operator, Northern Ohio Traction & Light Co.; res., 155 Rhodes Ave., Akron, Ohio.

*Richter, Henry, Asst. Development Engr., American District Telegraph Co.; res., 1542 Bryant Ave., New York, N. Y.

*Robertson, E. A., Sales Engineer, Westinghouse Electric & Mfg. Co.; res., 5404 Vernon Ave., St. Louis, Mo.

Sanborn, Warren E., Electrical Engineer, with M. E. Cooley, 86 Park Place, Newark, N. J.

Schantz, Leroy C., Patent Attorney, 903 1st National Bank Bldg.; res., University Club, Milwaukee, Wis.

*Scott, A. G., Electrical Commercial Salesman, W. G. Nagel Electric Co.; res., 2203 Lagrange St., Toledo, Ohio.

*Seeger, Charles P., Student, Washington University; res., 4410 Evans Ave., St. Louis, Mo.

Sekizawa, Fusatoyo, Electrical Engineer, Mitsubishi Dockyard & Engine Works, Kobe, Japan.

*Shanklin, George Bryan, Consulting Engineering Dept., General Electric Co., Schenectady, N. Y.

Smith, Owen Earl, Switchboard Operator, Station M, Portland Railway, Light and Power Co., Estacada, Ore.

*Stanton, Raymond Lewis, Substation Operator, Philadelphia Electric Co.; res., 4622 Cedar Ave., West Philadelphia, Pa.

*Strait, John Milton, Assistant in Electrical Measurements, Ohio State University; res., 2413 Neil Ave., Columbus, Ohio.

Swan, George Leslie, Assistant Electrician, John Hancock M. Life Insurance Co., Boston; res., 183 Lynn St., Peabody, Mass.

*Tennant, Joseph A., Electrical Engineer, 719 Chronicle Building, Houston, Texas.

*Terrell, John Alan, Instructor in Electrical Engineering and Physics, Rensselaer Polytechnic Institute, Troy; res., 478 Madison Ave., Albany, N. Y.

*Thayer, Goeffrey Rice, Catenary Designer and Elec. Line Inspector, Norfolk & Western R. R. Co.; res., 120 Summer St., Bluefield, W. Va.

*Towle, Thomas Stevens, Engineer, Cutler-Hammer Mfg. Co.; res., 183 14th St., Milwaukee, Wis.

*Uhl, Arthur William, George H. Gibson Co., New York; res., 285 Monroe St., Brooklyn, N. Y.

*Wahl, James Howard, Switchboard Operator, Whitestone Substation, Long Island Railroad Co.; res., 44 W. 13th St., Whitestone, N. Y.

*Waite, Leslie Osgood, Engineering Staff, Motive Power Dept., Interborough Rapid Transit Co.; res., 309 Park Ave., New York, N. Y.

*Washburn, Morgan, Jr., Engineering Dept., Cutler-Hammer Mfg. Co.; res., 183 14th St., Milwaukee, Wis.

*Weeks, John Randel, Jr., Telephone Engineer, Western Electric Co., 463 West St., New York, N. Y.

WILLARD, RUDOLPH H., Electrical Instructor, Norfolk & Western Ry. Co.; res., 111 Tazewell St., Bluefield, W. Va.

*WINFREE, EDWARD S., Switchboard Operator, Memphis Consolidated Gas and Electric Co.; res., 1360 Faxon Ave., Memphis, Tenn.

*WINSLOW, FRANK EDWARD, Student Engineer, Emerson Electric Co., St. Louis, Mo.

*WOLF, HERMAN CARL, Assistant Engineer, State Public Utilities Commission, Springfield; res., 113 Springer Ave., Edwardsville, Ill.

*YARDLEY, BERNARD VAN HORN, Engineer, Service Dept., Westinghouse Electric & Mfg. Co., Philadelphia, Pa.

Total 104.

*Former enrolled Students.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 29, 1916.

Alden, C. R., Detroit, Mich.
Ammen, W., New York, N. Y.
Barter, H. H. (Member), San Diego, Cal.
Bills, F. B., St. Louis, Mo.
Board, V. L., New York, N. Y.
Bowen, R. E., Elmira, N. Y.
Boyd, E. L., Mendon, Ill.
Boyd, R. L., Jacksonville, Fla.
Broadbent, W. W., Norwich, Conn.
Clegg, T. H., Philadelphia, Pa.
Connell, H. R., Brackenridge, Pa.
Coover, M. S., Three Forks, Mont.
Creager, F. L., Anderson, Ind.
Creesy, C. K., Takoma Park, D. C.
Crouse, J. L., (Member), Van Nest, N. Y.
Crowley, J. A., New York, N. Y.
Dillard, E. A., Birmingham, Ala.
Dittmar, R. A., Jr., Hannibal, Mo.
Dittrick, C. H., Cleveland, O.
Feige, C H., Tuinucu, Cuba.
Fitzgerald, J. G., Raleigh, N. C.
Fowler, W. D., Montreal, Que.
Frost, H. H., Chicago, Ill.
Gowen, J. M., Brooklyn, N. Y.
Grant, F. L., Jr., New York, N. Y.
Green, S. G., Columbus, Ga.
Groginski, P. S., College Station, Tex.
Guimares, A. R., Rio de Janeiro, Brazil.
Hamilton, B. P., New York, N. Y.
Hansson, A. S., Champagne S. Seine, France.
Hardy, G. E., Burlington, Vt.
Hartley, R. V. L., New York, N. Y.
Hartshorne, W. B., Hackensack, N. J.
Hartwell, E. L. (Member), Denver, Col.
Hight, E. S. (Member), Peoria, Ill.
Hutchinson, H. H., Vaudreuil Station, Quebec.
Jeffery, R. C., Schenectady, N. Y.
Jones, L. D., Schenectady, N. Y.
Keene, A. D., Schenectady, N. Y.
Kirchner, H. P., Niagara Falls, Ont.
Klag, F. W., Toledo, Ohio.
Korner, A. J., Vasteras, Sweden.
Latzer, F., New York, N. Y.
Love, J. E., Pierre, S. D.
MacDonald, D. D., New York, N. Y.
Maher, J. F., New York, N. Y.
Mathews, E. D. K., Ottawa, Canada.
McAlpine, D. D., Toronto, Ontario.
McClelland, E. R., Chicago Heights, Ill.
Millar, W. R., Feilding, N. Z.
Mizushi, F. M., Osaka, Japan.
Newman, R. C., San Francisco, Cal.
Palmer, W. S., Puunene, Mami, T. H.
Peatross, R. W., Jr., Dallas, Tex.
Peterson, A. J. A., Pittsburgh, Pa.
Pierce, N. C., Kilbourn, Wis.
Poyner, J. M., Baltimore, Md.
Pryde, D. S., San Antonio, Tex.
Ready, W. A., Preston, Cuba.
Reynolds, R. W., Oroya, Peru.
Ryan, W. J., Toronto, Ont.
Scheril, H., Ampere, N. J.
Schmidt, J. H., Cleveland, O.
Staubitz, L. P., Chicago, Ill.
Steindorff, K., Schenectady, N. Y.
Stephens, B. G. C., Dunedin, N. Z.
Stuart, L. M., Tenafly, N. J.

Sunier, W. H., Ft. Wayne, Ind.
Szafranski, B., San Francisco, Cal.
Tait, I. R., Montreal, Que.
Templer, G. M., Taranaki, N. Z.
Toy, J. I., Ft. Wayne, Ind.
Tsuchiya, S., Schenectady, N. Y.
Wade, M. L., Duncan, B. C.
Witzel, E. R., Groton, S. D.
Wray, E., New York, N. Y.
Total 76.

STUDENTS ENROLLED JANUARY 14, 1916

7781 Moore, F. A., Kans. St. Agric. Col.
7782 Butler, T. W., Purdue University
7783 Ratz, R. D., Univ. of Toronto
7784 McHugh, D. S., Kansas State Agricultural College
7785 Berg, B. L., Highland Park Coll.
7786 Oehmig, E. W., Ga. Inst. Tech.
7787 Bischoff, H. W., Columbia Univ.
7788 Guterman, H., Columbia Univ.
7789 Switzer, L. A., Bucknell Univ.
7790 Noble, C. S., Univ. of Wash.
7791 Grenland, A. S., Univ. of Wash.
7792 Gower, J. A., Jr., Carnegie Institute of Technology
7793 Caldwell, A. P., Jr., Mass. Institute of Technology.
7794 Powell, R. S., Univ. of Penna.
7795 Barney, E. J., Mass. Inst. of Tech.
7796 Gray, C., Washington Univ.
7797 Macdonald, R. W., Washington University
7798 Loery, W. W., Washington Univ.
7799 Monroe, W. P., Washington Univ.
7800 Stetler, F. E., Bucknell Univ.
7801 McLaughlin, H. L., W. Va. Univ.
7802 Herold, A., Kans. State Agri. Coll.
7803 Russell, C. H., Casino Tech. Night School.
7804 Spangler, F. L. P., Univ. of Kans.
7805 Van Auken, F. T., Columbia Univ.
7806 Long, C.C., Cooperative Engineering School
7807 Bardin, H. M., Univ. of Wash.
7808 McFarland, T. C., Univ. of Cal.
7809 Renaud, E., Armour Inst. of Tech.
7810 Weeth, E.P., Armour Inst of Tech.
7811 O'Grady, O.G., ArmourInst.Tech.
7812 Manock, F. D., Columbia Univ.
7813 Cameron, A. A., Univ. of Penna.
7814 Fronmuller, T. C., Univ. of Calif.
7815 Partsch, H. D., Univ. of Calif.
7816 Sakuma, F., Stanford University
7817 Mayeda, I., Stanford University
7818 Miwa, T., Stanford University
7819 Neill, E. L., Stanford University
7820 Mackie, D. W., Stanford Univ.
7821 Pathak, M. L., Univ. of Ill.
7822 Roloson, G. B., Univ. of Colo.
7823 Kuehl, A. A., Jr., Cooperative Engineering School
7824 Spiller, P., Cooper Union
7825 Gibbons, E. J., Syracuse Univ.
7826 Sullivan, A. J., Syracuse Univ.
7827 Minard, C. W., Syracuse Univ.
7828 Rawson, P. C., Kans. St.Agri.Coll.
7829 Woodward, E. S., Cooperative Engineering School
7830 Spratt,W.W.,WorcesterPoly.Inst.
7831 Whittaker, H. L., Cooperative Engineering School
7832 Rice, E. A., Cooperative Engineering School
7833 Costello, C. C., Cooperative Engineering School
7834 Pitman, I. G., Cooperative Engineering School
7835 Husted, D. R., Mass. Inst. Tech.
7836 Turner, C. E., Univ. of Texas
7837 Donaldson, C.A., Jr., Univ.of Tex.
7838 von Blucher, J. I., Univ. of Texas
7839 Darter, W. A., Univ. of Texas
7840 Baker, W. R. G., Union College
7841 Hazzard, W. S., Cornell Univ.
7842 Gorman, N. A., Cornell Univ.
7843 Bartolicius, L. W., Cornell Univ.
7844 Hambleton, R. L., Cornell Univ.
7845 Crandall, A. B., Cornell Univ.
7846 Cassidy, G. E., Cornell Univ.
7847 Strong, H. M., Cornell Univ.
7848 Trevor, K. R., Cornell Univ.
7849 Banning, H., Jr., Cornell Univ.
7850 Floodeen, E., Highland Park Coll.
7851 Smiley, L. D., Univ. of Illinois
Total 71.

EMPLOYMENT DEPARTMENT

NOTE: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-90. Vacancy for a man thoroughly familiar with all the details of manufacturing gauze wire brushes. Must know the machinery required. Excellent opportunity for the right man.

V-98. Good opportunity for a technical graduate, preferably one who has had several years' drafting or construction experience, skilled in preparation of drawings, and acquainted with switchboard detail and arrangement material; duties will consist mainly of substation layout work for high-tension transmission and distribution system. Salary to start about $100 per month, depending upon experience. Location Northern Illinois. Please give training, experience, etc.

V-99. A large Eastern steam railroad requires the services of an electrical engineer with experience in the installation and maintenance of electrical apparatus for various purposes, and who is familiar with general power plant practice. Salary about $2200. Please give age, training, experience and other details.

The United States Civil Service Commission has announced the following examinations to be held on the dates indicated.

March 15, 1916: Junior Mechanical or Electrical Engineer, Engineer Department at Large. (Students in mechanical or electrical engineering in colleges of recognized standing who expect to graduate not later than June, 1916, will be admitted to this examination, if otherwise eligible). Aid, Bureau of Standards, Aid, Coast and Geodetic Survey, Assistant Examiner, Patent Office, Assistant Inspector of Boilers, Steamboat-Inspection Service, Assistant Inspector of Hulls, Steamboat-Inspection Service, Computer, Coast and Geodetic Survey, Draftsman, copyist, topographic, Departmental Service, Draftsman, Engineer Department at large, Marine Engine and Boiler Draftsman, Navy Dept. Ship Draftsman, Navy Dept, Engineer, second class (or assistant) steam, Departmental Service, Forest Assistant, Forest Service. Industrial Teacher, Philippine Service. Laboratory Apprentice, Bureau of Standards. Local Inspector of Boilers, Steamboat Inspection Service.

April 12, 1916: Cadet Engineer, and Cadet Officer, Lighthouse Service. Civil Engineer and draftsman, Departmental Service. Computer, Nautical Almanac Office and Naval Osbervatory. Computer and Estimator, Supervising Architect's Office. Architectural draftsman, Supervising Architect's Office. Draftsman, copyist, Marine Engine and Boiler, Navy Dept. Draftsman, Copyist, Ship, Navy Dept. Draftsman, Mechanical, and Topographic, Panama Canal Service. Electrician, Departmental Service. Engineer, Indian Service. Engineer, first class, steam, Departmental Service. Junior Chemist, Departmental Service. Junior Engineer (Civil), Engineer Department at Large. Junior Engineer (mining), Bureau of Mines. Laboratory Assistant, Bureau of Standards. Scientific Assistant, Department of Agriculture.

Application forms and full information in regard to the above-named examinations may be obtained by addressing the U. S. Civil Service Commission, Washington, D. C.; or the Secretary of the Board of Examiners at the following-named places: Post Office, Boston, Mass.; Philadelphia, Pa.; Atlanta, Ga.; Cincinnati, O.; Chicago, Ill.; St. Paul, Minn.; Seattle, Wash.; San Francisco, Cal.; Customhouse, New York, N. Y.; New Orleans, La.; Honolulu, Hawaii; Old Customhouse, St. Louis, Mo.; Administration Building, Balboa Heights, Canal Zone; or the Chairman of the Porto Rican Civil Service Commission, San Juan, Porto Rico.

MEN AVAILABLE

402. Electrical Engineer, with ten years' experience in Western Colorado and Eastern Utah at railway, power and lighting work, especially competent in report work, wishes work at investigation and reporting in the above region or elsewhere. Thoroughly familiar with physical resources and commercial and financial connections in the territory.

403. A-1 Electrical Man; fifteen years' experience in construction, maintenance and repair shop. Two years as chief electrician at one of the largest mines and smelters in Mexico. Speaks and writes Spanish; strictly sober; single. Only those wanting absolutely first-class man need reply.

404. Electrical Engineer, usual training, six years' experience; desires employment at anything, irrespective of character.

405. Cable Engineer. Now employed as assistant to superintendent of underground construction of large central station company, desires position as superintendent with consulting engineer, contractor or smaller central station company. Has had experience in station and substation construction. Technical training; salary moderate.

406. Superintendent, with ten years' experience in operating and construction hydroelectric and steam power stations, substations and transmission lines; thorough knowledge of Spanish. Can take full charge of construction of power station, transmission and distribution. Willing to go anywhere, especially foreign projects.

407. Mechanical-Electrical Engineer, technical graduate, knowledge of shop costs, wage systems and efficiency methods. Has worked in engineering department, drafting room, and as practical machinist. Desires position as assistant to superintendent or works manager of growing concern where good character, ability, loyalty and application are assets; salary commensurate with position.

408. Manager-Superintendent or Chief Engineer. By man holding similar positions with large central station and having had charge of both operation and construction of plants, also organization and management of properties. Satisfactory records submitted and references given. Services available promptly; Mem. A. I. E. E.

409. Electrical Engineer, technical graduate, Cornell, 1913. Age 25. Two and a half years General Electric test, including steam turbines. At present in charge of one of testing sections. Available about March 1. Desires position with power company. Expect good salary and have no objection to hard work.

410. Manager. Has had fifteen years' experience in central station and industrial construction and operation. Has been particularly successful as application engineer and new business manager. Reason for desiring change, territory fully developed.

411. Technical Graduate, age 29, now holding responsible position with prominent New York law firm, desires connection with reliable electrical concern. Experienced manager, sales and executive. Qualified assistant to man of affairs, capable of writing concise business-getting letters, handling mass of details and systematizing office work.

412. Hydraulic and Electrical Engineer, McGill University, B.Sc., (1908). Just completed design, construction, operation, water supply system one and one-half million gallons per day from underground sources, including filtration and treating plant, for Panama-Pacific International Exposition. Responsible for design and construction nine well-known hydroelectric developments Oregon, Idaho, Washington, Western Canada.

413. Electrical Engineer for large firm of consulting engineers in the middle West desires change. Experience includes entire charge of design of isolated plants, including plans, specifications, estimates, preliminary reports, tests and superintendence; wiring layouts for office buildings, shops, grain elevators, etc.; three years in high-tension design. Age 31.

414. Electrical Engineer, 1914 graduate, test experience, now employed on public utility regulation and subway construction work, desires to locate with private firm, which will recognize industry and ability by promotion. Initial salary of less importance than permanency and future prospects of the position.

415. Electrical Engineer, degrees of E. E. and Master of Electrical Engineering. Several years' teaching experience. Also experience in apparatus design with power company. Would prefer position teaching, research laboratory, or design work, but will consider other work. Single, age 33; will go anywhere in U. S. or Canada.

416. Electrical Engineer, in charge of large industrial plant electrical and mechanical equipment, wishes to return to New York or vicinity. A good executive, accustomed to doing the things the other fellow cannot do and getting them done on time. Can purchase equipment to good advantage and install it so as to get best advantage from available floor-space. $2400. to start.

417. Electrical and Mechanical Engineer, with fourteen years' experience in the design and construction of direct- and alternating-current motors, generators and synchronous converters with large manufacturing companies, wants position as sales engineer to handle line of d-c. and a-c. machines and controllers. Technical graduate, age 31, married.

418. Electrical Engineer. Thirteen years' experience in design, construction and management of electric lighting, power and railway properties. Thoroughly familiar with estimates, reports, accounting systems, rates, etc. Has held positions of designing engineer, construction superintendent, and general manager. Capable of handling employees and successful in dealing with the public.

419. Engineer, with sixteen years' practise in design, construction and operation of electric utility and hydraulic mining properties, six years engineering and financial reports and appraisals, open for a position or associate connection with an established engineering firm, or position with operating company.

420. Electrical Engineer, technical graduate eastern university; eight years' experience testing electrical machinery. University instruction, editing and writing technical articles on industrial motor applications, electric railways and steam road electrifications, familiar with printing, engraving and preparation of copy. Available on reasonable notice.

421. Manager or Superintendent, Mem. A. I. E. E., age 42. Twenty-five years' experience in construction, installation and operation of large power plants in Europe and America. Has successful record; open for immediate engagement.

422. Engineer in charge of construction and maintenance in an industrial plant or for public service company. Ten years' experience in lighting, power, switchboard, power station and electrical testing layouts and installations. Technical graduate.

423. Electrical Engineer. Now designing engineer with street railway company; seeks position as engineer or superintendent with similar concern. Would enter commercial engineering work, preferably in line of power house equipment or electrical apparatus. Two years' experience with General Electrical Co., and four with present company.

424. Engineer with technical education, shop training, and commercial experience of the first order, desires a sale account for machinery of genuine merit. New York, Pittsburgh or Cleveland territory preferred.

425. A Mechanical-Electrical Engineer with a wide and successful experience in design, construction and management of power plants and distribution systems, will soon be open for engagement. Salary $2,700.

ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Exact Calculation of Electric Transmission Lines with Distributed Dielectric Admittance, and the Complex Hyperbolic Method. (in Esperanto). By A. E. Salazar. Washington, D. C., 1916. (Gift of Author.)

Iowa Electrical Association.' Proceedings of Annual Convention. 13-15, 1913-15. (Gift of Association.)

The Service of Information, United States Army, By G. P. Scriven. (Circular no. 8, Office of the Chief Signal Officer, 1915.) Washington, 1915. (Gift of War Dept.)

Water Power Projects, telephone, telegraph, power transmission lines in the National Forests. Washington, 1915. (Gift of U. S. Department of Agriculture.)

GIFT OF MASSACHUSETTS INSTITUTE OF TECHNOLOGY ELECTRICAL ENGINEERING DEPARTMENT

Experimental Researches on Skin Effect in Conductors. By A. E. Kennelly, F. A. Lewis and P. H. Pierce. (Bulletin no. 9, Electrical Engineering Dept., Research Division.) 1915.

Impedances, Angular Velocities and Frequencies of Oscillating Current Circuits. By A. E. Kennelly.

Mechanics of Telephone Receiver Diaphragms, as derived from their Motional Impedance Circles. By A. E. Kennelly and H. A. Affel. (Bulletin no. 8, Electrical Engineering Dept. Research Division.) 1915.

Receiving-end impedance of a conducting line loaded at both ends. By A. E. Kennelly.

UNITED ENGINEERING SOCIETY

Century of Invention of the Marquis of Worcester. By Charles F. Partington. London. 1825. (Purchase.)

Dynamometers. By F. J. Jervis-Smith. New York, 1915. (Purchase.)

Electric Elevators, their construction and operation. By Elmer G. Henderson. Chicago, 1915. (Purchase.)

Electroplating. By W. R. Barclay and C. H. Hainsworth, London, 1912. (Purchase.)

Elevators. By John H. Jallings. Chicago, 1915. (Purchase.)

Practical Electro-plating. By W. L. D. Bedell. Ed. 3. n.p. 1912. (Purchase.)

Public Utilities Reports, annotated. 1915, E. Rochester, 1915. (Purchase.)

Smoke Abatement and Electrification of Railway Terminals in Chicago. Report of the Chicago Association of Commerce Committee of Investigation on Smoke Abatement and Electrification of Railway Terminals. Chicago, 1915. (Gift of Chicago Association of Commerce.)

Telephone Appraisal Practice. By J. C. Slippy. Pittsburgh, 1915. (Purchase.)

Theoretical Elements of Electrical Engineering. Ed. 4. By C. P. Steinmetz. New York, 1915. (Purchase.)

Tramway Track Construction and Maintenance. By R. B. Holt. London, 1915. (Purchase.)

Wireless Time Signals. Issued by the Paris Bureau of Longitudes. London-N. Y., 1915. (Purchase.)

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LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.

*Deceased.

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20 Nassau Street, New York.
F. B. Crocker, Vice-President,
A. E. Kennelly, Secretary,
Harvard University, Cambridge, Mass.

C. A. Adams, E. B. Rosa,
B. A. Behrend, Charles F. Scott,
Louis Bell, Clayton H. Sharp,
James Burke, Samuel Sheldon,
Gano Dunn, C. E. Skinner,
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Louis Duncan, Charles F. Scott,
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L. L. Edgar, E. A. Wagner,
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Term expires July 31, 1916.
Schuyler Skaats Wheeler, Chairman,
Ampere, N. J.
Ralph D. Mershon, Frank J. Sprague.

Term expires July 31, 1917.
A. E. Kennelly, Robert T. Lozier.
S. G. McMeen.

Term expires July 31, 1918.
H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.
Charles F. Brush, William Stanley.
N. W. Storer.

Term expires July 31, 1920.
Carl Hering, Harris J. Ryan,
H. G Stott.

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1916.
C. O. Mailloux, L. T. Robinson,
Farley Osgood.

Term expires July 31, 1917.
B. A. Behrend, Paul M. Lincoln,
William McClellan.

Ex-Officio.

John J. Carty, President,
George A. Hamilton, Treasurer.
F. L. Hutchinson, Secretary.

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Ralph D. Mershon, Paul M. Lincoln.
C. O. Mailloux, John J. Carty,

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Samuel Sheldon, Harold Pender,
Edward D. Adams, W. I. Slichter,
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The chairman of the Institute's Code Committee.

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Calvert Townley, William McClellan.

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Charles F. Scott, Samuel Sheldon.

ON AMERICAN ELECTRIC RAILWAY ASSOCIATION COMMITTEE ON JOINT USE OF POLES.
Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON NATIONAL JOINT COMMITTEE ON OVERHEAD AND UNDERGROUND LINE CONSTRUCTION.
Farley Osgood, F. B. H. Paine,
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Michael I. Pupin.

ON NAVAL CONSULTING BOARD.
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Guido Semenza, N. 10 Via S. Radegonda, Milan, Italy.
Robert Julian Scott, Christchurch, New Zealand.
T. P. Strickland, N. S. W. Government Railways, Sydney, N. S. W.
L. A. Herdt, McGill Univ., Montreal, Que.
Henry Graftio, Petrograd, Russia.
Richard O. Heinrich, Genest-str. 5, Schoeneberg. Berlin, Germany.
A. S. Garfield, 67 Avenue de Malakoff Paris, France.
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.
John W. Kirkland, Johannesburg, South Africa.

LIST OF SECTIONS

Revised to February 1, 1916.

Name and when Organized	Chairman	Secretary
Atlanta................Jan. 19, '04	A. M. Schoen	H.E. Bussey, Third Nat. Bk. Bldg. Atlanta, Ga.
Baltimore.............Dec. 16. '04	J. B. Whitehead	L. M. Potts. Industrial Building, Baltimore, Md.
Boston.................Feb. 13, '03	L. L. Elden	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago.......................1893	W. J. Norton	Taliaferro Milton, 613 Marquette Building, Chicago, Ill.
Cleveland.............Sept. 27, '07	E. H. Martindale	Irving H. Van Horn, National Lamp Works, Nela Park, Cleveland, Ohio.
Denver...............May 18, '15	W. A. Carter	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor......Jan. 13, '11	Ralph Collamore	C. E. Wise, 427 Ford Bldg., Detroit, Mich.
Fort Wayne...........Aug. 14, '08	J. J. Kline	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Ind.
Indianapolis-Lafayette...Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca.................Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Los Angeles............May 19, '08	E. Woodbury	R. H. Manahan, 32 City Hall, Los Angeles, Cal.
Lynn..................Aug. 22, '11	G. N. Chamberlin	F. S. Hall, Gen.Elec.Co., West Lynn, Mass.
Madison...............Jan. 8, '09	M. C. Beebe	F. A. Kartak, Univ. of Wis., Madison, Wis.
Mexico...............Dec. 13, '07		
Milwaukee.............Feb. 11, '10	R. B. Williamson	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.............Apr. 7, '02	E. T. Street	Walter C. Beckjord, St. Paul Gas Light Co., St. Paul, Minn.
Panama...............Oct. 10, '13	William H. Rose	C. W. Markham, Balboa Heights, C. Z.
Philadelphia...........Feb. 18, '03	J. H. Tracy	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh.............Oct. 13, '02	T. H. Schoepf	G. C. Hecker, 436 Sixth Avenue, Pittsburgh, Pa.
Pittsfield..............Mar. 25, '04	M. O. Troy	F. R. Finch, General Electric Company, Pittsfield, Mass.
Portland, Ore..........May 18, '09	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Rochester.............Oct. 9, '14	E. L. Wilder	F. E. Haskell, 93 Monica Street Rochester New York.
St. Louis..............Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco.........Dec. 23, '04	A. H. Babcock	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady...........Jan. 26, '03	L. T. Robinson	F. W. Peek, Jr., Gen. Elec. Co., Schenectady, N. Y.
Seattle................Jan. 19, '04	C. E. Magnusson	C. E. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Spokane..............Feb. 14, '13	Victor H. Greisser	C. A. Lund, Washington Water Power Co., Spokane, Washington.
Toledo.................June 3, '07	George E. Kirk	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto...............Sept. 30, '03	D. H. McDougall	
Urbana...............Nov. 25, '02	P. S. Biegler	T. D. Yensen, Univ. of Illinois, Urbana, Ill.
Vancouver............Aug. 22, '11	R. F. Hayward	H. N. Keifer, Northern Electric Company, Ltd., Vancouver, B. C.
Washington, D. C.......Apr. 9, '03	R. H. Dalgleish	Arthur Dunlop, National Electric Supply Company, Washington, D. C.

Total 32

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas......Nov. 12, '09		
Alabama, Univ. of......Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of.....Mar. 25, '04	P. X. Rice	F. M. Ellington, University of Arkansas, Fayetteville, Ark.
Armour Institute........Feb. 26, '04	A. A. Oswald	J. F. Hillock, Armour Institute of Technology, Chicago, Ill.
Brooklyn Poly. Inst.,...Jan. 14, '16		
Bucknell University....May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	J. V. Kimber	H. A. Mulvaney, 1521 Hopkins Street, Berkeley, Cal.
Carnegie Inst. of Tech..May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of....Apr. 10, '08	W. A. Steward	R. H. Kruse, 75th and Main Streets, Cincinnati, Ohio.
Clarkson Col. of Tech...Dec. 10, '15	W. A. Dart	C. J. Dresser, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col. Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College.........Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized		Chairman	Secretary
Colorado, Univ. of	Dec. 16, '04	E. F. Peterson	Samuel J. Blythe, University of Colorado, Boulder, Colo.
Georgia School of Technology	June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College	Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of	June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College	Apr. 15, '03	F. H. Hollister	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of	May 18, '09		A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col.	Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agric. Col., Manhattan, Kansas.
Kansas, Univ. of	Mar. 18, '08	E. C. Arnold	E. C. Burke, 1214 Kentucky Street, Lawrence, Kansas.
Kentucky, State Univ. of	Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College	Apr. 5, '12	Rodman Fox	Frank H. Schlough, Lafayette College, Easton, Pa.
Lehigh University	Oct. 15, '02	A. F. Hess	R. W. Wiseman, Lehigh University, South Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of	Dec. 26, '06	A. A. Packard	E. V. Crimmin, Univ. of Maine, Orono, Me.
Michigan, Univ. of	Mar. 25, '04	U. M. Smith	N. F. Brown, University, of Michigan, Ann Arbor, Mich.
Missouri, Univ. of	Jan. 10, '03	K. Atkinson	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col.	May 21, '07	Taylor Lescher	J. A. Thaler Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts	Feb. 11, '10	R. V. Davis	R. L. Kelly, West Raleigh, N. C.
North Carolina, Univ. of	Oct 9 '14	P. H. Daggett	
Ohio Northern Univ.	Feb. 9 '12	H. H. Robinson	F. W. Evans, 302 E. Lincoln Avenue, Ada, Ohio.
Ohio State Univ.	Dec. 20, '02	R. G. Locket	D. A. Dickey, Ohio State University, Columbus, Ohio.
Oklahoma, Agricultural and Mech. Col	Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of	Oct. 11, '12	Clifford O. Oster	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon Agr. Col.	Mar. 24, '08	Winfield Eckley	Fred E. Pinn, Oregon Agric. College, Corvallis, Ore.
Penn. State College	Dec. 20, '02	J. E. Shreffler	Robert P. Meily, Pioneer House, State College, Pa.
Pittsburgh, Univ. of	Feb. 26, '14	G. W. Flaccus	Ralph C. Zindel, University of Pittsburgh, Pittsburgh, Pa.
Purdue University	Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Rensselaer Poly. Inst.	Nov. 12, '09	W. J. Williams	S. N. Galvin, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst.	Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col.	Mar. 14, '13	C. E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ.	Dec. 13, '07	A. B. Stuart	H. J. Rathbun, Stanford University, Cal.
Syracuse Univ.	Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of	Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin, Tex.
Throop College of Technology	Oct. 14, '10	J. W. DuMond	K.W. Rich, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute	Jan. 8, '15	V. Dixon	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of	Feb. 9, '12	W. S. Rodman	J.H. Moore, Dawsons Row, University, Va.
Wash. State Col. of	Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Coll. of Wash. Pullman, Wash.
Washington Univ.	Feb. 6, '04	P. C. Roberts	Charles A. Lieber, Washington University, St. Louis, Mo.
Washington Univ. of	Dec. 13, '12	E. C. Miller	Geo. S. Smith, Univ. of Washington, Seattle, Wash.
West Virginia Univ.	Nov. 13, '14	H. C. Schramm	C. L. Walker, West Virginia Univ., Morgantown, W. Va.
Worcester Poly, Inst.	Mar. 25, '04	R. M. Thackeray	C. C. Whipple, Worcester Polytechnic Institute, Worcester, Mass.
Yale University	Oct. 13, '11	P.G. von der Smith	S. R. Large, 343 Elm Street, New Haven, Conn.

Total 54.

American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXV | MARCH, 1916 | Number 3

A. I. E. E. MEETING, MARCH 10, 1916

The 319th meeting of the A. I. E. E., which will be a joint meeting with the New York Section of the American Electrochemical Society, will be held in the Engineering Societies Building, 33 West 39th Street, New York, on Friday evening, March 10, at 8:15 p.m.

The subject of the meeting will be Electrolysis, and two papers will be presented. On behalf of the A. I. E. E., a paper will be presented by Messrs. Burton McCollum, of the Bureau of Standards, and G. H. Ahlborn, entitled *The Influence of Frequency of Alternating or Infrequently Reversed Current on Electrolytic Corrosion.* This paper is published elsewhere in this issue of PROCEEDINGS, and advance copies are available on application to A. I. E. E. headquarters. On behalf of the A. E. S., a paper will be presented by Prof. William H. Walker of the Massachusetts Institute of Technology, entitled "Electrolytic Corrosion of Metals."

ANNUAL CONVENTION AT CLEVELAND, JUNE 27-30, 1916

Upon the recommendation of the Meetings and Papers Committee, the Board of Directors has selected Cleveland as the meeting place for the 1916 Annual Convention, which will be held June 27th to 30th, 1916.

President Carty has appointed the following members of the Annual Convention Committee: E. H. Martindale, Cleveland, chairman, Howard Dingle, Cleveland, E. J. Edwards, Cleveland, Allard Smith, Cleveland, E. W. P. Smith, Cleveland, H. L. Wallau, Cleveland, I. H. Van Horn, Cleveland, Farley Osgood, Newark, N.J., J. Franklin Stevens, Philadelphia, A. S. McAllister, New York, L. T. Robinson, Schenectady, and John H. Finney, Washington.

COMMITTEE ON PROGRAM FOR SECTION DELEGATES, ANNUAL CONVENTION, CLEVELAND

Acting under Section 60A of the Institute by-laws, Chairman Hornor of the Sections Committee has appointed the following sub-committee to prepare a program of questions of interest to the Institute Sections for discussion at the conference of Section Delegates at the Annual Convention in Cleveland, June 27th to 30th, 1916:

J. Lloyd Wayne, 3rd, Indianapolis, Ind., E. H. Martindale, Cleveland, Ohio, and J. H. Tracy, Philadelphia, Pa. Mr. Hornor is *ex officio* a member of this sub-committee.

Although it is the duty of this sub-committee to prepare the program of questions for discussion, under the by-laws it devolves upon the Section Delegates themselves to submit to the chairman of the Sections Committee at least 60 days in advance of the convention such questions as in their opinion should be discussed.

Under the constitution the Section Delegates are the chairmen of Sections in office at the time the convention is held.

PACIFIC COAST CONVENTION, SEATTLE, WASHINGTON, SEPTEMBER 5-8, 1916

Upon the request of the Seattle Section, and with the approval of the other Pacific Coast Sections and the Meetings and Papers Committee, the Board of Directors at its December meeting authorized the Pacific Coast Convention for 1916 to be held in Seattle, under the auspices of the Seattle Section, the date to be decided by the Section.

The Executive Committee of the Seattle Section has decided to hold the convention the same week as the convention of the Northwest Electric Light and Power Association, and the dates decided upon for the two meetings are September 5, 6, 7 and 8. The local committees in charge of the preliminary arrangements are already at work, and announcements giving definite information regarding the program, division of time with the Association, and other details will be published in subsequent issues of the PROCEEDINGS.

COMING SECTION MEETINGS

Baltimore.—March 10, 1916. Paper: "Heavy Electric Traction," by J. F. Layng.

Boston.—March 7, 1916, Franklin Union. Subject: The Oscillograph.

April 4, 1916, Franklin Union. Subject: Industrial Motion Pictures.

Chicago.—March 27, 1916. Subject: Electric Vehicles.

Cleveland.—March 20, 1916. Chamber of Commerce Building. Paper: "Cleveland's White Way Lighting," by C. G. Beckwith.

Detroit-Ann Arbor.—March 10, 1916, Detroit Engineering Society Rooms. Paper: "The Electric Furnace," by E. Crossby.

March 17, 1916, Hotel Statler. Annual Banquet.

Ithaca.—March 24, 1916. Annual Banquet of Section. Chief speakers will be President J. J. Carty of the Institute, and Judge Frank Irvine of the New York State Public Service Commission.

Milwaukee.—March 21, 1916. Address by Dr. John Brashear on "Astronomical Instruments."

Pittsburgh.—March 14, 1916, Auditorium of Engineers Society of Western Pennsylvania, Oliver Building. Paper: "The Regulation of Series Street Lighting Systems," by W. R. Woodward. Joint meeting with Illuminating Engineering Society.

Rochester.—March 24, 1916. Paper: "Factory Handling of Direct-Current Motors," by Edward F. Davison and E. Darwin Smith, Jr.

Schenectady.—March 7, 1916. Paper: "Iron Losses in Direct-Current Machines," by B. G. Lamme.

March 21, 1916. Paper: "Atoms and Molecules," by Albert C. Crehore.

Spokane.—March 17, 1916. Paper: "Rotary Condensers," by V. H. Greisser.

April 21, 1916. Paper: "Transformers—Installation, Operation and Maintenance," by M. W. Birkett.

St. Louis.—March 9, 1916. Paper: "Safety and the Human Element at Hawthorne," by A. W. Hitchcock.

April 12, 1916. Paper: "Railroad Day and Night Signals," by B. H. Mann.

Vancouver.—March 16, 1916. Paper: "Electric Dredging and Hydraulic Sluicing," by F. D. Nims. Joint meeting with N. E. L. A.

April 13, 1916. Paper: "Water Powers of British Columbia," by G. R. G. Conway. Joint meeting with N. E. L. A. Section.

CONSTITUTIONAL AMENDMENTS

During the past three years the desirability of amending the constitution of the Institute has been considered by the Board of Directors. Each year

the Board has authorized the appointment of a committee to consider and report upon the advisability of undertaking a revision. In order to ascertain the extent of the sentiment in favor of a revision, the present Constitutional Revision Committee invited suggestions and comments, through the medium of circular letters and notices in the monthly Institute PROCEEDINGS, from all officers of the Institute, the past-presidents, all Section officers, and the membership at large. The result of this was the receipt of a considerable number of suggestions, all of which received careful consideration by the committee.

It was decided by the Board last fall that a revision is desirable, not on account of any serious defects in the present constitution, which, on the contrary, has been pronounced to be an exceedingly sound instrument, but largely to correct minor discrepancies which have arisen through the development of the Institute, necessitating changes in the administration of its affairs.

The committee made a preliminary report to the Board of Directors in December, which was discussed at length, and referred back to the committee with suggestions. The final report, embodying the proposed amendments as formulated and recommended by the committee, was submitted to the Board of Directors at the January meeting. At this meeting the Board approved the proposed amendments and recommended their adoption by the membership. The amendments, accompanied by explanatory notes and a ballot, will be mailed to each member about March 15. In order to be adopted, 30 per cent of the entire membership must vote upon them, and 75 per cent of the vote cast must be in favor of adoption. For this reason, and also because of the desirability that the vote shall be representative of the general views of the membership, each member is urged to mark and mail his ballot promptly, in accordance with the directions printed thereon.

NATIONAL PREPAREDNESS

On January 21, 1916, at the call of the President, the Board of Directors of the Institute held a special meeting to act upon an invitation from the President of the United States to nominate from the Institute membership, for the approval of the Secretary of the Navy, a representative from each State of the Union to act in conjunction with representatives from the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers and the American Chemical Society, for the purpose of assisting the Naval Consulting Board in the work of collecting data for use in organizing the manufacturing resources of the country for the public service in case of emergency. After a full discussion of the subject, President Carty was empowered to select the nominees on behalf of the American Institute of Electrical Engineers, and to assist him in making the selection, a list of suggested names was prepared by the Board and referred to Mr. Carty.

The correspondence between the President of the United States and President Carty follows:

The White House, Washington, D. C.
Jan. 13, 1916.

My dear Sir:

The work which the American Institute of Electrical Engineers has done through its members on the Naval Consulting Board is a patriotic service which is deeply appreciated. It has been so valuable that I am tempted to ask that you will request the Institute to enlarge its usefulness to the Government still further by nominating for the approval of the Secretary of the Navy a representative from its membership for each state in the Union to act in conjunction with representatives from the American Society of Mechanical Engineers, the American Society of Civil Engineers, the American Chemical Society, and the American Institute of Mining Engineers, for the purpose of assisting the Naval Consulting Board in the work of collecting data for use in organizing the manufacturing resources of the country for the public service in case of emergency. I am

sure that I may count upon your cordial cooperation.

With sincere regard,
Cordially yours,
WOODROW WILSON

Mr. John J. Carty, President,
American Institute of Electrical
Engineers, New York.

New York, Jan. 19, 1916.

To the President,
Washington, D. C.

I have the honor to acknowledge your letter of the 13th of this month requesting that the American Institute of Electrical Engineers nominate for the approval of the Secretary of the Navy, a representative from its membership for each state in the Union to act in conjunction with representatives of certain other societies for the purpose of assisting the Naval Consulting Board in the work of collecting data for use in organizing the manufacturing resources of the country for the public service in case of emergency.

Upon the receipt of your letter, I called a meeting of the Board of Directors of the Institute to take the necessary action to comply with your request. Knowing the patriotic spirit which actuates all of the members of our Institute, I am confident that prompt and effective action will be taken to put into effect the plan which was outlined in your letter, and I am sure that your expression of appreciation of the service which the American Institute of Electrical Engineers has done through its members on the Naval Consulting Board will be received with feelings of satisfaction by our membership throughout the country.

Respectfully yours,
JOHN J. CARTY,
President.

The Institute's nominees were notified of their nomination on February 18, and the prompt and cordial acceptances received at the time this notice goes to press fully justify the confidence expressed in President Carty's reply to President Wilson.

NATIONAL RESERVE CORPS OF ENGINEERS

As announced in the September issue of the PROCEEDINGS, committees were appointed last spring by five national engineering societies to assist the War Department in the formation of an engineer reserve corps of the United States Army, and a joint committee, consisting of the chairmen of the committees of the different societies, was also formed.

The following report of the Joint Committee has been transmitted to the Institute for publication, for the information of the membership, by the Institute's Committee, consisting of Messrs. B. J. Arnold, Chairman, John Harisberger, Ralph D. Mershon, A. M. Schoen and Charles W. Stone:

To the Special Committees of
American Society of Civil Engineers,
American Institute of Mining Engineers,
American Institute of Electrical Engineers,
American Institute of Consulting Engineers,
American Society of Mechanical Engineers,
on the Organization of a National Engineer Reserve.

Dear Sirs:

The Joint Committee (consisting of the chairmen of your several committees) formed under the authority of the five societies, in order to facilitate the carrying out of the organization of an engineer reserve as part of the military forces of the United States, for which work you were appointed, now begs leave to report as follows:

The Committee has been in personal communication with the Secretary of War, the officers of the General Staff, the officers of the War College, and with the Hon. Geo. E. Chamberlain, Chairman of the Senate Committee on Military Affairs, and the Hon. James Hay, Chairman of the House Committee on Military Affairs.

As the result of these interviews there has been incorporated in the draft of the legislation proposed by the Secretary of War and included also in the bills drawn by the committees of the Senate and of the House, a provision for the organization of an officers' reserve on broad lines, including an engineer reserve. As now drawn these bills provide that an officer shall be commissioned for a period of five years with rank up to and including that of major, after passing such requirements of character and qualifications as shall be prescribed by the President. The bill also provides that a certain amount of duty with pay shall be performed each year by the officers in the reserve.

The Committee is waiting for the

Navy Department to formulate its plan for the increase in the naval forces, and as soon as a decision has been reached by that Department and the Committee is in possession of the facts, the Committee will take up the question of the organization of an engineer reserve for the Navy, similar to that contemplated for the Army.

It is the intention of the Committee to attend any Congressional hearings that may be had on the bill or bills introduced for the creation of an engineer reserve.

Prior to the enactment of the necessary legislation, no enrolment for the proposed reserve can be made.

Very truly yours,
WM. BARCLAY PARSONS,
Chairman,
HENRY S. DRINKER,
BION J. ARNOLD,
WM. H. WILEY,
RALPH D. MERSHON.

The members of the different engineering societies will be communicated with later by the committees on Engineer Reserve Corps, referred to above, after the necessary legislation has been passed by Congress and the War Department plans have been more definitely formulated.

In announcements which appeared in the public press early in February the activities of these committees, officially representing the national engineering societies in the organization of an engineer reserve corps, were somewhat confused with those of a local committee of engineers in New York and vicinity under whose auspices a series of lectures by U. S. Army Engineers has been arranged, as announced elsewhere in this issue. The two activities are entirely independent though mutually helpful.

LECTURES ON MILITARY ENGINEERING

A course of seven free lectures on Military Engineering, under the auspices of a committee of New York engineers, began on Monday evening, February 14, 1916, at the Engineering Societies Building, New York, and will continue every Monday until the completion of the course. The lectures are being given by Captains Thomas M. Robins, Richard T. Coiner and Edward D. Ardery of the Corps of Engineers, United States Army.

This course is under the direction of Major General Leonard Wood, and is designed to assist those who desire to enter the engineering battalion which will be formed at Plattsburg next summer. The members of the national engineering societies in New York and vicinity and other engineers interested were invited to attend.

The subjects of the lectures are as follows:

1. Organization and duties of Engineers in war, and what Engineers in civil life will be called upon to do in the defence of the United States.
2. The service of reconnaissance, including surveying, mapping and sketching, photography and map reproduction.
3. Field fortifications, sieges and demolitions.
4. Seacoast defences and battle-field illuminations.
5. The construction, maintenance, and repair of roads, bridges, and ferries; the selection and preparation of fords.
6. The selection, laying out and preparation of camps and cantonments; the service of general construction; and the special services, including all public work of an engineering nature which may be required in a territory under military control.
7. The construction, operation and maintenance of railways under military control and the construction and operation of armored trains.

The interest in the lectures proved to be so great that a parallel series of lectures was begun on the first night in one of the lecture rooms of the Engineering Societies Building to accommodate those who could not get into the auditorium, but even this was not sufficient, as over five hundred engineers were turned away from the building. Since then the second course of lectures which was begun on the evening of February 14 has been transferred to

the building of the American Society of Civil Engineers, 220 West 57th Street, New York, and a third course, starting on February 21, is being given at 5:30 p.m. in the auditorium of the Engineering Societies Building. More than 3100 applications have been received by the committee from engineers desiring to attend the lectures.

The audiences have been addressed by Captain Dorey, U. S. A., who is in charge of the Plattsburg Training Camp, and by members of the First Training Regiment, organized by men who attended the camp last summer. Major General Wood is expected to speak at one of the meetings of each course.

A. I. E. E. MEMBERSHIP

BY P. M. LINCOLN

There are many things that can be done by engineers in the aggregate that would be impossible to any engineer as an individual. This is one of the fundamental reasons underlying the existence of the technical society. The only way by which any individual engineer can take part in those activities that pertain to the engineer in the aggregate is through engineering societies.

It is true that many of the activities that are carried on by engineering societies are not, in general, such as will appeal to the selfish motives of the individual engineer; they are rather altruistic in character. It is not to be thought of, however, that the only argument that will have weight with the prospective member of our Institute, is one that is purely selfish. There are, of course, selfish reasons why electrical engineers should join our Institute, but it is not the selfish reason that I wish to emphasize in this short paragraph. It is rather my intention to emphasize the altruism that actuates our engineering societies—among them, our own Institute—in the performance of many of their functions.

Take, for instance, the Naval Consulting Board, whose members were recently designated for appointment by the leading technical societies of America. The activities of this Board are not such as to appeal to the selfish motives of the membership of our technical societies; but every member ought to be proud of the recognition accorded to engineers in general by the request that came to us from the Secretary of the Navy for the designation of the members of this board. This is only one instance. The engineering societies are continually being called on to perform similar duties—duties that can be performed only by the engineers in the aggregate.

MEMBERSHIP COMMITTEE

The following figures show the number of applications for admission to the Institute received from the beginning of the fiscal year, May 1, 1915, to February 24, 1916, inclusive:

Sections	Applications Received May 1, 1915 to February 24, 1916.	Per Cent of Present Section Membership
Atlanta	4	9
Baltimore	4	4.5
Boston	15	4
Chicago	27	6
Cleveland	15	9
Denver	22	51
Detroit-Ann Arbor	7	5.5
Fort Wayne	5	13.5
Indianapolis-Lafayette	3	6.5
Ithaca	4	7
Los Angeles	6	4
Lynn	3	3
Madison	3	9
Milwaukee	7	6
Minnesota	1	1
Panama	6	9
Philadelphia	19	6
Pittsburgh	32	8
Pittsfield	7	5
Portland	2	2.5
Rochester	3	5
St. Louis	17	15
San Francisco	17	6
Schenectady	32	9
Seattle	5	6
Spokane	1	2
Toledo	3	12
Toronto	9	6
Urbana	6	15
Vancouver	2	3.5
Washington, D. C.	7	8

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Total number of members located in Section territory		4107
Percentage for Section territory		7%
Received from applicants outside Section territory	297	
Total number members outside Section territory		4044
Percentage for outside territory		7%
Totals	591	8151

PUBLICATIONS OF INTERNATIONAL ENGINEERING CONGRESS, 1915

The Committee of Management, International Engineering Congress, 1915, announces that the volume on Mechanical Engineering is ready for distribution and the members who have subscribed to this volume will soon receive it.

The other volumes will be issued as rapidly as possible. Owing to the large amount of material to be reprinted, and the thousands of copies to be bound, the work cannot be carried on with greater speed. However, it is hoped that within two months the entire set will be completed.

Members who did not send in their final selections may be disappointed in not securing all the volumes they might have had in mind, and at this date the Committee has decided to close the lists for certain volumes which have been sent to the press. It may be possible to supply members who would apply at this late hour with copies of volumes which have not gone to press.

W. A. Cattell, Secretary
425 Foxcroft Building,
San Francisco, Cal.

FOURTH MIDWINTER CONVENTION, NEW YORK, FEBRUARY 8-9, 1916

The fourth Midwinter Convention of the Institute, held at the Institute headquarters, Engineering Societies Building, New York, was opened on Tuesday morning, February 8th, with an introductory address by President J. J. Carty, and in that session and the three following sessions on Tuesday afternoon and the morning and afternoon of Wednesday, eleven papers were presented and discussed, in accordance with the program of the convention printed in the February Proceedings, in which all of these papers were published. President Carty's address and the discussions of the papers will appear in future issues.

The Institute convention was followed by the sessions of the Illuminating Engineering Society's midwinter convention on February 10 and 11, and many Institute members availed themselves of the invitation extended by the Society to attend these sessions. The total registered attendance at the Institute midwinter convention was 671.

On Tuesday evening the A. I. E. E. subscription dinner-dance in the grand ball-room of the Hotel Astor was attended by 425 members and guests, this being a larger attendance than in any previous year.

DIRECTORS' MEETING, NEW YORK, FEBRUARY 9, 1916

The regular monthly meeting of the Board of Directors of the Institute was held in New York on Wednesday, February 9, at 4:30 p.m.

There were present: President John J. Carty, New York; Past-President Paul M. Lincoln, Pittsburgh, Pa.; Vice-Presidents F. S. Hunting, Fort Wayne, Ind., Farley Osgood, Newark, N. J., C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William McClellan, New York; Managers H. A. Lardner, New York, B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y., Frederick Bedell, Ithaca, N. Y., Bancroft Gherardi, New York, A. S. McAllister, New York, John H. Finney, Washington, D. C., John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa.; Treasurer George A.

Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $11,659.03 was ratified.

Announcement was made of the following appointments on the Convention Committee, which will have charge of the arrangements for the Annual Convention in Cleveland, June 27-30, 1916: E. H. Martindale chairman, Howard Dingle, E. J. Edwards, Allard Smith, E. W. P. Smith, H. L. Wallau, I. H. Van Horn, all of Cleveland, and Farley Osgood, J. Franklin Stevens, A. S. McAllister, L. T. Robinson, and John H. Finney, members of the Board of Directors.

The report of the Board of Examiners of its meeting held on February 3 was read and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners, one Member was transferred to the grade of Fellow and three Associates were transferred to the grade of Member, one applicant was elected as a Fellow, five as Members and 81 as Associates, and 83 students were ordered enrolled, in accordance with the lists published in this issue of the PROCEEDINGS.

Professor M. I. Pupin, who had served for one year as the Institute's representative upon the Engineering Foundation, was unanimously renominated for election by the Board of Trustees of the United Engineering Society for the current calender year. (Dr. Pupin was accordingly elected at the February meeting of the Board of Trustees of the United Engineering Society.)

A considerable amount of other business was transacted, reference to which will be found in future issues of the PROCEEDINGS.

PAST SECTION MEETINGS

Boston.—February 8, 1916, City Club. Seventh Annual Banquet of engineering societies in Boston. Addresses as follows: (1) "The Engineer and the Commonwealth," by Governor Samuel W. McCall; (2) "Engineers in National Defence," by Colonel W. E. Craighill, U. S. A.; (3) "Engineers in National Defence—A Second Viewpoint," by Wm. Barclay Parsons; (4) "The Slides on the Panama Canal," by John R. Freeman; (5) "An Evening's Journey Among the Stars," by John A. Brashear. Attendance 382.

Chicago.—January 24, 1916. Address by Mr. H. N. Foster on "The Modern Seven-League Boots." Attendance 80.

Cleveland.—January 17, 1916, Chamber of Commerce. Paper: "Electric Drive for Rolling Mills," by F. B. Crosby. Attendance 37.

Denver.—January 22, 1916, Denver Athletic Club. Paper: "Commercial Telephone Rates," by L. G. Gomez. Attendance 38.

Detroit-Ann Arbor.—January 15, 1916, University of Michigan, Ann Arbor. Paper: "Mechanical Analogies in Electricity and Magnetism," by W. S. Franklin. Attendance 150.

Fort Wayne.—January 20, 1916, Mizpah Temple. Address by Mr. Kettering on "Modern Automobile Tendencies." Attendance 69.

Indianapolis-Lafayette.—January 21, 1916, Indianapolis. Paper: "Some Recent Developments in High-Voltage Transmission," by C. F. Harding. Attendance 48.

Ithaca.—January 14, 1916, Franklin Hall, Cornell University. Address by Mr. Albert W. Hull on "The Dynatron." Mr. Hull illustrated his talk with a working dynatron and gave demonstrations of the apparatus. Attendance 100.

Los Angeles.—January 25, 1916, Chamber of Commerce. Paper: "Open-Air Generating Stations," by Ralph Bennett. Attendance 30.

Milwaukee.—January 12, 1916, Republican House. Illustrated address by Mr. Francis A. Vaughn on "Shall the City of Milwaukee Own

Its Street Lighting System?" Attendance 90.

February 9, 1916, Republican House. Illustrated address by Mr. Arthur Simon on "The Design and Application of Electric Magnets." Attendance 125.

Minnesota.—January 24, 1916, Elks' Club, Minneapolis. Papers: (1) "Lighting of an Art Gallery," by A. L. Abbott; (2) "Report on Tests of Lighting Fixtures at the New Railroad Building, St. Paul," by Charles Klapper. Attendance 32.

Panama.—January 23, 1916, Balboa Heights, C. Z. Subject: "The First Year's Operation of the Permanent Power System of the Panama Canal." Speakers: Messrs. B. R. Grier, W. L. Hersh, Carl W. Markham, Hartley Rowe and R. H. Fischer. Attendance 30.

Philadelphia.—December 2, 1915, Franklin Institute. Paper: "Magnetic Investigations of Iron and Steel," by John D. Ball. Joint meeting with Franklin Institute. Attendance 70.

December 13, 1915, Engineers Club. Subject: "Philadelphia's Public and Industrial Systems of Education for Electrical Artisans." Symposium by Messrs. Charles F. Bauder, Clayton W. Pike, W. B. Creagmile, H. N. Stillman, J. Leeds Clarkson and H. P. Liversidge. Attendance 75.

January 10, 1916, Engineers Club. Paper: "Electrical Engineering in the Coal Industry," by George F. Metz. Attendance 85.

Pittsfield.—December 30, 1915, Hotel Wendell. Paper: "The Education for a Career in Electrical Engineering," by Prof. W. I. Slichter. Attendance 80.

January 24, 1916, Hotel Wendell. Paper: "High-Voltage Problems," by R. J. McClelland. Attendance 125.

February 10, 1916, G. E. Restaurant. Paper: "The Application of Electron Emission to Electrical Engineering," by Saul Dushman. Paper was illustrated with lantern slides and numerous experiments. Attendance 95.

Rochester.—January 28, 1916, Rochester Engineering Society Rooms. Paper: "Rates," by H. C. Deffenbaugh. Attendance 34.

Schenectady.—January 18, 1916, Edison Club Hall. Illustrated lecture by Mr. Elmer A. Sperry on "The Electrically Driven Gyroscope and Its Uses." Attendance 450.

January 25, 1916, Edison Club Hall. Illustrated lecture by Mr. R. J. McClelland on "The Physical Development of a Large Western Hydro-Electric Transmission System." Attendance 300.

February 10, 1916, Union College Gymnasium. Illustrated lecture by Dr. John A. Brashear on "The Great Telescopes of the World and the Discoveries Made by Their Use." Attendance 1250.

Seattle.—January 18, 1916, Central Building. Paper: "The Keokuk Development," by W. D. Shannon: paper illustrated by lantern slides. Attendance 38.

Spokane.—December 17, 1915, W. W. P. Co. Building. Paper: "Some Phases of Line Construction," by C. W. Miller. Attendance 46.

January 21, 1916, W. W. P. Co. Building. Paper: "Diversity of Heating and Cooking Loads," by H. B. Peirce. Attendance 33.

St. Louis.—February 9, 1916, Engineers Club. Paper: "The Cleveland Street Railway Situation," by F. W. Doolittle. Attendance 93.

Vancouver.—January 14, 1916, Board of Trade Rooms. Paper: "Electricity in the Mining Industry," by C. N. Bebee; paper illustrated by lantern slides. Attendance 31.

January 20, 1916, Board of Trade Rooms. Paper: "Telephone Equipment in Mines," by H. N. Keifer. Attendance 25.

Washington.—January 11, 1916, Cosmos Club. Paper: "Economics of Water Powers, with Special Reference to the Great Falls Project," by Francis Weller. Attendance 156.

PAST BRANCH MEETINGS

University of California.—January 19, 1916. Addresses as follows: "Application of the Motion Picture to Engineering," by Mr. McCann; "Application of the Diversity Factor," by Mr. Quick. Attendance 24.

Clarkson College of Technology.—February 2, 1916. Address by Mr. Shock on "The Interrelation of Engineers on a Power Development Project." Attendance 23.

Highland Park College.—January 19, 1916, College Chapel. Address by Mr. C. A. Sears on "Construction and Operation of the Keokuk Installations." Attendance 268.

University of Kansas.—January 19, 1916, Marvin Hall. Illustrated address by Mr. A. R. Wilson on "The Main Power Plant of the Kansas City Metropolitan Street Railway Company." Attendance 18.

Kansas State Agricultural College.—January 20, 1916, Old Chapel. Illustrated lecture by Mr. D. C. Tate on "The Lighting of the Panama-Pacific Exposition." Attendance 230.

State University of Kentucky.—January 28, 1916, Mechanical Hall. Papers: (1) "Methods of Ignition," by A. B. Huff; (2) "The Owen Magnetic Car," by R. E. Handley; (3) "Lighting and Starting Systems," by W. Lail. Attendance 19.

University of Maine.—January 19, 1916, Aubert Hall. Paper: "Modern Telephone Systems," by Mr. Bell. Attendance 30.

January 27, 1916, Bangor House, Bangor. Annual Banquet of the Branch. Attendance 21.

February 2, 1916, Hannibal Hamlin Hall. Addresses as follows: "Electrical Propulsion of Ships," by Mr. Partridge; "History and Principles of Wireless Telegraphy," by Burke Bradbury. Attendance 42.

University of Nebraska.—January 5, 1916, Electrical Laboratory. Address by Mr. L. E. Hurtz on "The Business Side of Engineering." Attendance 31.

North Carolina College of Agricultural and Mechanical Arts.—January 19, 1916. Illustrated lecture on "The Transformer", and demonstration by Messrs. G. C. Cox, Hester and Henry.

January 26, 1916. Explanation and demonstration of different types of d-c. armature windings by Messrs. T. H. Holmes and L. B. Jenkins. Attendance 28.

February 2, 1916. Demonstration of improvements in incandescent lamp lighting by Messrs. Millwee, Moore and Robinson. Address by Mr. R. M. Hooper on "Storage Batteries." Attendance 20.

Ohio Northern University.—January 12, 1916, Dukes Memorial. Addresses as follows: "Concentric Wiring," by S. O. Pratt; "Household Electrical Appliances," by Mr. Slusser. Attendance 24.

January 26, 1916, Dukes Memorial. Addresses as follows: "Safeguarding the Use of Electricity in Mines," by Mr. Fultz; "Gasoline Auto Electric Equipment," by Mr. Barnett. Attendance 20.

February 9, 1916, Dukes Memorial. Addresses as follows: (1) "Student Apprentice Courses," by K. B. MacEachron; (2) "The Engineer in Politics," by F. W. Evans; (3) "The Relationship of Hydroelectric Development to Social Life of Community," by Mr. Goldberg. Attendance 28.

Oregon Agricultural College.—January 13, 1916, Corvallis, Ore. Paper: "Central Stations," by R. U. Steelquist. Attendance 20.

January 27, 1916, Corvallis, Ore. Paper: "Steam vs. Electricity as Applied to Railroads." Attendance 27.

University of Virginia.—January 25, 1916, Mechanical Laboratory. Addresses as follows: (1) "Motion Picture Projection Apparatus," by A. W. Wright; (2) "Details of the Manufacture of Mazda C Lamps," by J. H. Moon; (3) "Norfolk and Western

Electrification," by J. K. Peebles, Jr. Attendance 18.

Yale University.—January 21, 1916, Electrical Laboratory. Paper: "Making and Testing Electric Cables," by Henry W. Fisher. Paper was illustrated by lantern slides, and samples of materials were exhibited. Attendance 120.

PERSONAL

MR. C. G. COX, who was formerly associated with a prominent Diesel engine manufacturer in St. Louis, has been appointed district manager in St. Louis for the McIntosh Seymour Corporation, with headquarters in the Railway Exchange Building.

OBITUARY

J. RAE WILSON, Assoc. A. I. E. E., lost his life on January 22, 1916, in a wreck caused by a snowslide on the Great Northern Railway in the Cascade Mountains, near Corea, Wash. Mr. Wilson was connected with the Vancouver office of the Canadian Westinghouse Company as erecting engineer. He was elected an Associate of the Institute on November 8, 1907.

LOUIS DUNCAN, Ph.D., Fellow and Past President of the Institute, consulting engineer, died February 13, 1916, at his home in Pelham Manor, N. Y., in his 54th year. He was born in Washington, D. C., and graduated from the United States Naval Academy in 1880, being appointed an ensign three years later. In the same year he was sent to Johns Hopkins University to take a graduate course in physics and electricity, taking part in special studies and investigations with the late Professor Rowland which led to the determination of the ohm as the international unit of electrical resistance. In 1887 he received the degree of Doctor of Philosophy from the university and became a member of the faculty, resigning from the navy to accept the appointment. Dr. Duncan organized and took charge of the course of electrical engineering at Johns Hopkins, continuing in this position fourteen years. Meanwhile he accomplished much important consulting engineering work as a member of the firm of Sprague, Duncan and Hutchinson, his associates being Frank J. Sprague and Cary T. Hutchinson. He was consulting engineer for the electrification of the Baltimore tunnels of the Baltimore and Ohio Railroad and the equipment of the Third Avenue system in New York. Later he was consulting engineer for the New York City Rapid Transit Commission. Dr. Duncan had been an Associate of the Institute since July 12, 1887. He was elected President for 1895-96, and was re-elected for the term 1896-97. During the Spanish-American War, President McKinley appointed Dr. Duncan an aid in forming a battalion of engineers, and he became Major of the First Volunteer Engineers. In 1899 the Massachusetts Institute of Technology erected a new electrical laboratory, and Dr. Duncan was asked to establish the new electrical engineering course. He remained as head of the department until 1904. At the time of his death he was a member of the consulting engineering firm of Duncan, Young and Company, New York. Dr. Duncan was an honorary member of the Franklin Institute, and a member of the Mathematical Society of France and the Physical Society of France.

RECOMMENDED FOR TRANSFER, FEBRUARY 3, 1916

The Board of Examiners, at its regular monthly meeting on February 3, 1916, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

TO THE GRADE OF MEMBER

BUSWELL, JAMES M., General Manager, San Joaquin Light & Power Corp., Fresno, Cal.

KINGSBURY, JOHN McLEAN, Electrical Engineer, Secretary and Treasurer, Kingsbury Gas Electric Motor Car Co., New York, N. Y.

PEASLEE, W. D., Consulting Engineer, Portland, Ore.

PRICE, JOHN B., Price Electric & Machinery Co., Richmond, Va.

TRANSFERRED TO THE GRADE OF FELLOW FEBRUARY 9, 1916

The following Member of the Institute was transferred to the grade of Fellow at the meeting of the Board of Directors on February 9, 1916.

CROMWELL, LEWIS W., Electrical Engineer, American Zinc Co. of Tenn., Mascot, Tenn.

FELLOW ELECTED FEBRUARY 9, 1916

LACKIE, WILLIAM WALKER, Engineer and Manager, Electricity Dept., Glasgow Corporation, 75 Waterloo St., Glasgow, Scotland.

TRANSFERRED TO THE GRADE OF MEMBER FEBRUARY 9, 1916

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on February 9, 1916.

DOGGETT, LEONARD A., Professor of Electrical Engineering, U. S. Naval Academy, Annapolis, Md.

PENROSE, CHARLES, Engineer in charge of Construction, Station "A-2," Philadelphia Electric Co., Philadelphia, Pa.

WIGGERT, JOHN F., Designing Electrical Engineer, Homestake Mining Co., Lead, S. D.

MEMBERS ELECTED FEBRUARY 9, 1916

CRANSTON, HARRY DOW, Engineer, Frank L. Strong Machinery Co., 64-68 Calle Echague, Manila, P. I.

DANLEY, ROBERT JOEL MASON, Manager, Sultepec Electric Light & Power Co., Tuloca, Mexico.

FEND, ROLAND S., Chief Engineer, Woods Motor Vehicle Co.; res., Illinois Athletic Club, Chicago, Ill.

PALMER, JOEL C. R., Telephone Engineer & Patent Expert, Patent Dept., Western Electric Co., 463 West St., New York, N. Y.

SCHOTT, R. A., Chief Engineer, Virginian Power Co., Charleston, W. Va.

ASSOCIATES ELECTED FEBRUARY 9, 1916

ALBRECHT, HERMAN CARL, Superintendent, Station Construction, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

*ARNDT, REGINALD, Sales Engineer, American Carbon & Battery Co., East St. Louis, Ill.

ASAKURA, GENJI, Electrical Engineer, Kinugawa Hydro-Electric Power Co., Tokyo, Japan.

AYARS, WILLIAM STEWART, Professor of Electrical and Mechanical Engineering, Nova Scotia Technical College, Halifax, N. S.

*BARTGIS, CHARLES PHILIP, Engineer, American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

BEARCE, EDWIN FREEMAN, Chief Engineer, Mead Pulp & Paper Co.; res., Masonic Temple, Chillicothe, O.

BLAND, ALVIN M., Instructor of Mechanical Drawing, Bliss Electrical School, Takoma Park, Washington, D. C.

*BOEGEHOLD, EDWIN SWART, Engineer in Charge of High Voltage and Mechanical Testing, Electrical Testing Laboratories, New York, N. Y.

*BUCHANAN, WILLIAM B., Demonstrator in Electrical Engineering, University of Toronto; res., 484 Euclid Ave., Toronto, Ontario.

CALLAHAN, G. E., Bedford, Virginia.

CAMERON, JAMES SOMERVILLE, Superintendent of Plant, Northern Electric Co. Ltd., 121 Shearer St., Montreal, Quebec.

COUSINS, RUSSELL JOHN, Inspector of Electric Locomotives, Norfolk & Western Railway Co., Bluestone; res., 207 Frederick St., Bluefield, W. Va.

*DAVIS, RANCISCO HAROLD, Salesman of Appliances, Washington Water Power Co.; res., E. 914 Nora Ave., Spokane, Wash.

*DAVISON, THOMAS EDWIN, Head of Motor-Generator Section, Testing Dept., General Electric Co.; res., 718 Avenue A., Schenectady, N. Y.

DE COU, BENJAMIN S., Assistant Manager, James G. Biddle, Philadelphia, Pa.; res., 144 E. Oak Ave., Moorestown, N. J.

*DOBSON, CECIL F., Operator, Great Falls Power Co., Great Falls, Mont.

DOHERTY, ROBERT ERNEST, Designing Engineer, A. C. Engineering Dept., General Electric Co., Schenectady; res., 140 Vley Rd., Scotia, N. Y.

*DONNOHUE, JOHN JAY, Power Department, Utah Power & Light Co., 524 Kearns Bldg., Salt Lake City, Utah.

DOWNING, ROBERT B., Wireman, Panama Canal, Corozal, Canal Zone.

*EDWARDS, G. D., Telephone Transmission Engineering, Western Electric Co., 463 West St., New York, N. Y.

EVANS, RICHARD WILLIAM, Instructor in Mathematics and Physics, University of Akron, Akron, O.

FINKELNBURG, EDGAR H., Draftsman, Milwaukee Electric Railway & Light Co.; res., 124 Harmon St., Milwaukee, Wis.

*FINLEY, ROBERT BYRON, Instructor, Towne Scientific School, University of Pennsylvania, Philadelphia, Pa.

*FISHER, FRANK EUGENE, Designing Electrical Engineer, Diehl Manufacturing Co.; res., 310 Chilton St., Elizabeth, N. J.

*FLANSBURG, P. LEROY, Safety Supervisor, E. I. du Pont de Nemours Co., Haskell, N. J.

FOULKROD, RAYMOND, Student Engineer, Bell Telephone Co. of Pennsylvania, 1230 Arch St., Philadelphia, Pa.

FRANCY, CLARK WILSON, Electrician, Steubenville & E. Liverpool Ry. & Lt. Co., Steubenville; res., Toronto, Ohio.

FROST, WALTER HERBERT, Engineering Dept., New York Edison Co., New York; res., 138 5th Ave., New Rochelle, N. Y.

GRIDLEY, SIDNEY DIAS, Sales Engineer, Electric Storage Battery Co.; res., 5418 Walnut St., Philadelphia, Pa.

*GRIFFIN, RONALD CLARENCE, Office Asst. to Supt. of Elec. Distribution Dept., Pacific Gas & Electric Co.; res., 943 Cypress St., Oakland, Cal.

GROSS, ARTHUR WILLIAM, Editor of Handbooks, Booklets, etc., Publication Bureau, General Electric Co.; res., 103 Barrett St., Schenectady, N.Y.

HACKENSMITH, IRWIN CLARK, Telegraph and Telephone Inspector, Interstate Commerce Commission, Kansas City, Mo.

HALE, CLINTON BAKER, Foreman, Electric Shop, Navy Yard, New York, N. Y.; res., 62 Van Reypen St., Jersey City, N. J.

HARDY, ABLY WOLVERTON, Assistant Telephone Engineer, Corporation Commission of Oklahoma; res., 705 East Fifth St., Oklahoma City, Okla.

*HARRIS, CLIFFORD BLAINE, Freewater, Oregon.

*HENRY, PERCY CHANDLER, Electrical Dept., Illinois Steel Co.; res., 420 Adams St., Gary, Ind.

HESS, LAWRENCE JERE, Assistant Chief Electrician, Illinois Steel Co., Joliet Works, Joliet, Ill.

HILL, CYRUS GILES, Electrical Engineer, Chicago Telephone Co.; res., 2537 Michigan Ave., Chicago, Ill.

*HOBBS, MAURICE HILL, Power Plant Operator, Great Falls Power Co., Big Falls Dam, Great Falls, Mont.

HOGG, CHARLES JOSEPH, Line Assignor, New England Tel. & Tel. Co., Brookline; res., 19 Edge Hill St., Roxbury, Mass.

HOWLETT, WALTER HERBERT, Electrical Engineer, Mangaweka Town Board, Mangaweka, Rangitikei, New Zealand.

*IDE, CHARLES EDWARD, Cadet Engineer, Toledo Railways and Light Co.; res., 1043 W. Woodruff Ave., Toledo, Ohio.

*IIDA, TADASHI, Electrical Draftsman, Illinois Steel Co., Joliet Works; res., 917 Benton St., Joliet, Ill.

*JAMES, WILLIAM GORDON, Instructor of Electrical Engineering, University of Maine, Orono, Maine.

*JONES, KENNETH BURR, General Electric Test, General Electric Co.; res., 205 Seward Place, Schenectady, N. Y.

KAASE, WILLIAM ERNEST, Asst. to General Foreman of Meter Dept., New York Edison Co., New York; res., 710 E. 3rd St., Brooklyn, N. Y.

KELLER, ARNOLD, Power House Foreman, Cornucopia Mines Co., Cornucopia, Ore.

KENWORTHY, BOWDEN LAKIN, Switchboard Wireman, Power House, Cohoes Company; res., 29 McElwain Ave., Cohoes, N. Y.

*KOPFER, WILLIAM BUDDEE, Caney, Kansas.

*LULL, LINFORD COREY, JR., Clerk, Pacific Light & Power Corp.; res., 605 So. Harvard Blvd., Los Angeles, Cal.

LUTHER, GEORGE D., Soliciting Agent, Electric Storage Battery Co.; res., The Lancaster, 1765 Sherman St., Denver, Colo.

MITRA, HIMANSU M., Electrician-in-charge, Cossipore Power Station, Calcutta Electric Supply Corp., Cossipore, Calcutta, India.

MOFFATT, DOUGLAS R., Assistant Chief Electrician, Michigan Steel Castings Co., Guoin St., Detroit, Mich.

MUÑOZ, CECIL MIGUEL, General Manager, Harry Alexander, Inc.; res., 28 East 61st St., New York, N. Y.

NAKAYAMA, HISAO, Professor of Electrical Engineering, Neiji College of Technology, Tobata, Fukuoka-ken, Japan.

NEWLIN, EARL MORTIMER, Illuminating Engineering, New York Edison Co., 15th St. & Irving Place, New York, N. Y.

NICKENIG, CHARLES WILLIAM, Wireman, Interborough Rapid Transit Co., New York; res., 462 Eleventh St., Brooklyn, N. Y.

ORMSON, BOGI HOLM, Chief Electrician, Ruby Gulch Mining Co., Whitcomb, Mont.

POPE, NESTOR A., Operator, Rio de Janeiro Tramway, Light & Power Co. Ltd., Rio de Janeiro, Brazil, South America.

POPPE, THOMAS W., Chief Electrician, General Vehicle Co., Long Island City; res., 651 Humbolt St., Brooklyn, N. Y.

*PRINCE, D. C., Case Man, State Public Utilities Commission of Illinois; res., 502 S. 2nd St., Springfield, Ill.

*RICH, ALVIN RALPH, Assistant Head of Rheostat Test, General Electric Co.; res., 9 Eagle St., Schenectady, N. Y.

*ROGERS, CLARENCE BLOSS, In Charge Lamp Testing Bureau, Electrical Testing Laboratories, 80th St. & East End Ave., New York, N. Y.

SACHS, JOHN BALTZER, JR., Chief Electrician, American Car & Foundry Co.; res., 310 E. 11th St., Berwick, Pa.

SAHM, PAUL A. B., Cable Draftsman, Interborough Rapid Transit, 600 W. 59th St., New York, N. Y.

*SCHWARTING, HARRY FRED, Asst. to Chief Elec. Engr., American Car and Foundry Co.; res., 3520 N. 9th St., St. Louis, Mo.

*SEBAST, FREDERICK M., Post Graduate Student, Rensselaer Polytechnic Institute, Troy; res., 111 Third Ave., Albany, N. Y.

SMITH, MORRIS B., Engineer, Underwriters' Laboratories, Inc.; res., 303 Kellogg St., Syracuse, N. Y.

*SNYDER, CARL JAUDON, Engineer, Omaha Electric Light & Power Co., Omaha, Nebr.

*STETLER, A. M., Supt. of Substations and Power Houses, New York State Railways; res., 494 Grand Ave., Rochester, N. Y.

STEWARD, JOHN LEVAN, Experimental Laboratory Work, U. S. Light & Heat Corp.; res., 930 Cleveland Ave., Niagara Falls, N. Y.

TAKATORI, TAKEO, Electrical Engineer, Mitsui & Co. Ltd., 25 Madison Ave., New York, N. Y.

*TAPPAN, FRANK GIRARD, Instructor in Electrical Engineering, Cornell University; res.,Forest Home,Ithaca,N.Y.

TERRY, R. H., Relief Operator, Milwaukee Electric Railway & Light Co.; res., 158 Fifteenth St., Milwaukee, Wis.

THORNE, HOWARD OLWIN, Electrical Engineer, Westinghouse Electric Mfg. Co., W. 23rd St., New York, N. Y.; res., 194 Mountain Way, Rutherford, N. J.

*TUCKER, BURTON FLOYD, General Superintendent, Central Illinois Public Service Co., Mattoon, Ill.

*VANDERFIELD, EDWARD WRIGHT, Telephone Engineer, Western Electric Co., Hawthorne Station; res., 324 S. Marshfield Ave., Chicago, Ill.

*WALL, RUPERT, Foreman, Brighton Substation, Great Western Power Co., Sacramento, Cal.

*WINSHURST, HAROLD E. C., Designing Engineer, Diehl Manufacturing Co.; res., 91 W. Jersey St., Elizabeth, N. J.

WINTER, EDWIN MORTON, Foreman, Day Inspection Force, Crocker-Wheeler Electric Co., Ampere; res., 48 Main St., E. Orange, N. J.

*YEH, TING SHIEN, Instructor in Electrical Engineering and Applied Mechanics, Hunan Polytechnic Institute, Changsha, Hunan, Chian.

Total 81.

*Former enrolled Students.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before March 31, 1916.

Ames, G. B., Tallahassee, Fla.
Andrews, J. K., Pittsfield, Mass.
Armstrong, G. H., Pittsburgh, Pa.
Bartlett, L. (Member), Denver, Colo.
Beaufore, W. C., Detroit, Mich.
Beebe, G. L., Coldwater,Mich.
Bosson, F. N. (Fellow), Calumet, Mich.
Bouldin, W. K., Coopers, W. Va.
Bradford, C. C., Niagara Falls, N. Y.
Brown, H. A., Fayetteville, Ark.
Brown, L. H., Ithaca, N. Y.
Brown, W. S., Baltimore, Md.
Candee, A. H., East Pittsburgh, Pa.
Carpenter, E. S., Gilman, Ill.
Cooper, A. B. (Fellow), Toronto, Ont.
Cooper, S. B., East Pittsburgh, Pa.
Cooper, W. H., Mono Lake, Cal.
Curren, A. J., Elyria, O.
Darrow, L. H., New York, N. Y.
Davis, D. G., Hoboken, N. J.
Deane, L. E., Muskegon, Mich.
Dearborn, R. J., New York, N. Y.
Derry, H. G., Denver, Colo.
Dolson, F. O. (Member), Bishop, Cal.
Emerson, A. T., Seattle, Wash.
Finks, G. H., Gilliam, W. Va.
Finney, J. R., Pittsburgh, Pa.
Forman, A. H., Morgantown, W. Va.
Fortin, P. R., Schenectady, N. Y.
Fulk, C. M., Schenectady, N. Y.
Gallagher, H. J., San Francisco, Cal.
Gerard, H. J. A., East St. Louis, Ill.
Gifford, W. S., New York, N. Y.
Gillette, G., Wilmington, N. C.
Groff, F. A., Brooklyn, N. Y.
Hall, A. J. (Member), E. Pittsburgh, Pa.
Halliday, T. W., Rupert, Idaho.
Hammond, J. H., Jr. (Member), Gloucester, Mass.

Hardy, G. E., Steubenville, O.
Hare, K. R. (Member), New York, N.Y.
Harold, J. J. (Member), New York, N.Y.
Hawk, L. L., Cleveland, O.
Hickok, R. D. (Member), Cleveland, O.
Hill, W. W. (Member), Auburn, Ala.
Hinterpohl, A., New York, N. Y.
Inglis, M. M., Port Arthur, Ont.
Jain, R. S., Cleveland, O.
Jennings, F. R., Detroit, Mich.
Johnson, W. M. Jr., Takoma Park, D.C.
Jones, A. K., San Ramon, C. R.
Kellogg, G. H., San Francisco, Cal.
Kinard, C. A., Westfield, Mass.
Kneisly, H. L., Temple, Tex.
Kopp, O. H., New York, N. Y.
Kunse, R. M., Ft. Wayne, Ind.
Leisenring, J., Springfield, Ill.
Lenz, C. O. (Fellow), New York, N. Y.
Letts, L. W. G., Opotiki, N. Z.
Lewis, R. A., Denver, Colo.
Luecke, F. H., Gilman, Ill.
Lynn, E. K., Jr., East Pittsburgh, Pa.
Malmgren, A. G., New Haven, Conn.
Maxfield, L. S., New York, N. Y.
McCarty, F. A., Melbourne, Australia
McRobbie, H. W., Seattle, Wash.
Morris, R. M., Durango, Colo.
Nau, P. B., Cleveland, O.
Neff, G. C., Prairie du Sac, Wis.
Odendahl, R., Frood Mine, Ont.
Outes, E. S., Buenos Aires, A. R.
Packman, M. E., Valparaiso, Ind.
Price, M. N., Baltimore, Md.
Rugheimer, R. R., Bluefield, W. Va.
Russell, H. S., Denver, Colo.
Schwartz, B., St. Louis, Mo.
Secor, H. W., New York, N. Y.
Shu, S. J., Nanking, China.
Simpson, R. E., Hartford, Conn.
Slauson, H. L., Jr., Duquesne, Pa.
Spangenberg, O. C., New York, N. Y.
Spray, L. W., Ft. Wayne, Ind.
Stephenson, H. A., St. John, N. B.
Stigant, S. A., Manchester, England.
Stone, D. D., Flint, Mich.
Thiele, E. A., Maybrook, N. Y.
Umansky, L. A., Schenectady, N. Y.
Vales, A. R., New York, N. Y.
Wahlberg, N. A., East Pittsburgh, Pa.
Ward, C. W., Pittsburgh, Pa.
Waters, W. A., Whangarei, N. Z.
Werner, P. L., Glassport, Pa.
Whittaker, C. C., East Pittsburgh, Pa.
Wilson, C. E., Schenectady, N. Y.
Total 93.

STUDENTS ENROLLED FEBRUARY 9, 1916

7852 Ranes, G. O., Okla. A. & M. Coll.
7853 Wylie, R., Univ. of Michigan.
7854 von Nostitz, E., Univ. of Mich.
7855 Wolfe, C. L., Univ. of Oklahoma.
7856 Graff, A. A., Univ. of Illinois.
7857 Sinclair, C. T., Lehigh Univ.
7858 Spengler, R. A., Mass. Inst. Tech.
7859 Morrison, E.C., Clemson Agri.Coll.
7860 Campbell, L.O., Clemson Agri.Coll.
7861 Barre, M. L., Clemson Agri. Coll.
7862 Neil, W.H., Jr., Clemson Agri. Coll.
7863 Banks, D. H., ClemsonAgri. Coll.
7864 Boggs, L. A., Clemson Agri. Coll.
7865 Odom, R. J., Clemson Agri. Coll.
7866 Woods, E. T., Clemson Agri. Coll.
7867 Amme, D. A., Clemson Agri. Coll.
7868 Tolger, D. F., Clemson Agri. Coll.
7869 Wright, R. F., ClemsonAgri.Coll.
7870 Logan, E. A., Columbia Univ.
7871 Leighton, F. T., Columbia Univ.
7872 Baush, R. O., Columbia Univ.
7873 Cooper, H. G., Jr., ColumbiaUniv.
7874 Jensen, K. R., HighlandPark Coll.
7875 Johnson, A.N., Kans.St. Agri.Coll.
7876 Pharr, M. A., Jr., Ga. Sch. Tech.
7877 Swasey, C., Yale University.
7878 Mitchell, R. W., Mass. Inst. Tech.
7879 Dresser, C.J., Clarkson Coll.Tech.
7880 Zaugg, F. S., Seattle Engg. Sch.
7881 Maine, H.A., Clarkson Coll. Tech.
7882 Shreffler, J. E., Penna. St. Coll.
7883 Moyer, H. R., Penna. State Coll.
7884 Neely, G. L., Penna. State Coll.
7885 Pettee, A. D., Mass. Inst. Tech.
7886 Weiler, E. G., Univ. of Illinois.
7887 Jolliffe, O. P., West Va. Univ.
7888 Phinney, J.G., Kans. St. Agri. Coll.
7889 Fawver, A., Seattle Engg. Sch.
7890 Spencer, T., Univ. of Calif.
7891 Brockman, C., OhioNorthernUniv.
7892 Bedell, W.B., Ohio NorthernUniv.
7893 Gronvold, I. J., Seattle Engg. Sch.
7894 Pierson, P.R., Clarkson Coll. Tech.
7895 Dart, W. A., Clarkson Coll. Tech.
7896 Stevenson, A. M., Carnegie Inst. Tech.

7897 Stason, E. B., Mass. Inst. Tech.
7898 Miller, L. N., Kans. St. Agri. Coll.
7899 Redding, A. D., Univ. of Pitts.
7900 Taylor, J. G., Highland Park Coll.
7901 Pollak, H. C., Univ. of Wisconsin.
7902 Smith, A. G., Univ. of Calif.
7903 Ballard, G. L., Univ. of Wisconsin.
7904 Lancto, W., Clarkson Coll. Tech.
7905 Krotzer, J. E., Univ. of Pittsburgh
7906 Peth, J. C., Univ. of Pittsburgh.
7907 Wentz, J. F., Lehigh University.
7908 Bedford, L. N., Clarkson College of Technology.
7909 Gumm, L. M., Univ. of Illinois.
7910 Steinmayer, A. G., Univ. of Ill.
7911 Henderson, F. S., Univ. of Illinois.
7912 Beltz, J. S., Univ. of Illinois.
7913 Fink, A. B., Ga. School Tech.
7914 Rosenblatt, S. H., Univ. of Cal.
7915 Glann, C., Mass. Inst. Tech.
7916 Reynolds, H. V., Univ. of Cal.
7917 Grant, C. T., Univ. of Illinois.
7918 Hyndman, R., Jr., Univ. of Ill.
7919 Morrison, K. W., Clarkson College of Technology.
7920 Nungesser, R. A., Case School of Applied Science.
7921 Haman, D. A., Bucknell Univ.
7922 McDonald, K. M., Mass. Inst. Tech.
7923 McAllister, G. M., Ohio Northern University.
7924 Williams, E. C., Lehigh Univ.
7925 Callicutt, J. M., Univ. of Texas.
7926 Blair, W. C., Univ. of Texas.
7927 Anderson, A. J., Univ. of Texas.
7928 Rishell, G. L., Penna. State Coll.
7929 Cloke, P. R., Clarkson Coll. Tech.
7930 Cayey, E. V., Clarkson Coll. Tech.
7931 Caldwell, D. M., N. Y. Elec. Sch.
7932 Hammar, A., N. Y. Elec. School.
7933 Carter, E. O., Okla. A. & M. Coll.
7934 McCormick, J. R., Bucknell Univ.

Total 83.

EMPLOYMENT DEPARTMENT

NOTE: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-100. Draftsmen wanted for large hydroelectric development: Electrical, experienced in general layout and switchboard work. Mechanical, experienced in reinforced concrete and structural steel design. Give full information, including age, education, experience and salary desired.

V-109. Vacancy for a meter man to check and test single-phase and polyphase watt-hour meters. Please give experience in full and salary desired.

V-110. Draftsmen with experience on electrical apparatus, motors, generators, switchboards, transformers, controllers, etc. Address Chief Clerk, Engineering Department, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Penna.

MEN AVAILABLE

426. Electrical Engineer, technical graduate, industrial electrical specialist, thoroughly experienced in the design, construction and operation of the electrical equipment of modern industrial projects; executive experience. At present employed.

427. Position wanted in Ohio by graduate electrical engineer, now employed. Age 28. Three years' commercial experience, also miscellaneous shop and engineering experience. Equipment specification engineer with Bell telephone system nearly three years. Engineering work preferred, but will consider commercial work. Excellent ability, good personality.

428. Chief Electrician, large machinery manufacturing corporation, ten

years' experience a-c. and d-c. applications, desires larger field. Four years in present position. Age 28; married. Evening school student electrical engineering. Have superintended installation and construction of a-c. and d-c. industrial power plants.

429. Well-known electrical engineer with large American manufacturer and fourteen years' experience in this country and abroad desires to go into partnership for establishing consulting engineering office in New York or Chicago. Splendid opportunity for a bright young engineer with capital.

430. Electrical Engineer, age 30, married. Fourteen years' experience, operation, installation, maintenance and repair shops. Thoroughly familiar with every commercial type of electricity meter. Capable of estimating labor and construction costs. Thorough knowledge of substation layouts. Salary $1800.

431. An experienced electrical engineer, writer and teacher, wishes to make a change September 1. Not a narrow specialist. If you are looking for a man who knows the fundamentals and how to impart them to others, my record will interest you.

432. Electrical Engineer, 1904 graduate, now teaching in a New York City college, has time available for outside research or consulting work. Would like to associate himself with an electrical engineer. Initial pay no object. Experience includes shop work, railroad signal installation, general electrical contracting and teaching of electrical engineering.

433. Electrical Engineer, six years' electrical experience, including G. E. test, wiring, illumination and teaching of practical engineering. Desires position with live contractor or consulting engineer. Good record; salary moderate; age 28. Desires larger field; prefers position demanding hard work.

434. Electrical Engineer. Age 29. Nine years construction and maintenance. Desires position with industrial or railway company. Experienced in switchboard and substation apparatus. Capable of handling men on construction and maintenance work. Middle West preferred.

435. Electrical Engineer, Mem. A. I. E. E., Mem. A. S. M. E. Sixteen years' experience embracing drafting, design of power plants, transmission systems; illuminating and electrical engineering in connection with industrial plants, with a considerable amount of steam engineering. Six years in responsible charge.

436. Engineer, desires to locate with railway or power company. Technical knowledge, augmented with practical experience, consisting of maintenance, installation, design, construction and manufacture of railway and power house apparatus.

437. Electrical Engineer, age 30, technical graduate, with ten years' operating, construction and engineering experience on power plants, transmission lines, cars and equipment, who is at present in the employment of a large Eastern railroad, is open for a position as sales engineer.

438. I am an electrical engineer with a thorough knowledge of power stations and distribution systems, both lighting and railway, appraisal, corporation finance and accounting. I am at present employed but desire a field of larger endeavor with holding company, consulting engineer on development and report work, or as assistant to executive.

439. Electrical Engineer, Manager or Superintendent; American; age 45; married; K. T. Eighteen years' experience in design, construction and operation of electric light and power properties. Has held all positions, from humblest to that of manager. Desires position as manager of small company or superintendent of construction in larger one. Available March 15.

440. Graduate Electrical Engineer, eight years' experience, construction and operation of power houses and substations, valuations of public utilities, special investigations and reports.

441. Electrical Engineer, Mem. A. I. E. E., technical graduate, with ten years' experience in consulting engineering work in New York, with thorough knowledge of illumination, isolated plant design and electric construction work, desires change, with manufacturing or construction concern preferred.

442. Engineer, age 33, with technical training and broad mechanical and electrical experience, seeks responsible connection. Eight years with construction departments of large concerns, ranking as wireman to engineer in charge. Five years with manufacturing company in charge of production, tests and installations of machinery. Two years power and substation operating.

443. Electrical Engineer, technical graduate, broad experience in construction, maintenance and operation of steel mill electrical equipment. Can get

efficiency out of men and equipment. Experience in Latin-American countries. Speaks Spanish. Can leave on reasonable notice; location no object.

444. Electrical-Mechanical Engineer. Mem. A. I. E. E. Has been chief engineer, manager, construction foreman and emergency mechanic. Technical graduate with E. E. degree. Age 32; married.

ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Laboratory Manual of Alternating Currents. By L. C. Eddy. New York, Van Nostrand, 1915. (Gift of author.)

A small manual for laboratory experiments by students, issued to be used as supplementary to elementary text books. W.P.C.

Modern Industrial Lighting. New York, 1912. (Gift of National Electric Light Association.)

National Electric Light Association. 38th Annual Convention. Papers, Reports and Discussions. 4 vols. New York, 1915. (Exchange.)

Southwestern Electrical and Gas Association. Proceedings 10th Annual Convention, 1914. Houston, Tex., 1914. (Exchange.)

Sperry Gyro-stabilizer for ships. n.p. n.d. (Gift of Elmer Sperry.)

Telephone Pioneers of America. Proceedings of 4th Annual Convention, 1914. (Gift of Telephone Pioneers of America.)

United Engineering Society

Continuous Current Electrical Engineering. By W. T. Maccall. London, 1915. (Purchase.)

Handbuch der Elektrizität und des Magnetismus. Band III, pt. 2; Band IV, pt. 2. By L. Graetz. Leipzig, 1915. (Purchase.)

Kompendium der Röntgenaufnahme und Röntgendurchleuchtung. By F. Dessauer & B. Wiesner. Ed. 2., 2 vols. Leipzig, 1915. (Purchase.)

Shot Firing in Coal Mines by Electricity Controlled from Outside. (U. S. Bureau of Mines, Technical Paper 108) Washington, 1915. (Purchase.)

Specification and Design of Dynamo-Electric Machinery. By Miles Walker. London-N. Y. 1915. (Purchase.)

Telephone and Telephone Exchanges, their invention and development. By J. E. Kingsbury. London, 1915. (Purchase.)

La Transmission Electrique de la Force entre Kriegstetten et Soleure exécutée par la Société des Ateliers de Construction D'Oerlikon. Rapport. By H. F. Weber. Zurich, 1888. (Gift of Carl Hering.)

Water Power Engineering. Ed. 2. By Daniel W. Mead. New York, 1915. (Purchase.)

The Watt-hour Meter. By W. M. Shepard & A. G. Jones. San Francisco, 1910. (Purchase.)

Gift of Joseph Struthers

Cowles Electric Smelting and Aluminum Company and Alanson T. Osborn, appellants, vs. Francis P. Lowrey, Executor of the last will and testament of Grosvenor P. Lowrey deceased, Appellee. Appeal from the United States Circuit Court for the Northern District of Ohio. 1896.

Electric Smelting and Aluminum Company Complainant, vs. The Pittsburgh Reduction Company, Defendant. Decision of U. S. Circuit Court of Appeals, n.d.

Gift of Arthur Worischek

Schwartze, Th. Katechismus der Elektrotechnik. 1883.

OFFICERS AND BOARD OF DIRECTORS, 1915-1916.

PRESIDENT.
(Term expires July 31, 1916.)
JOHN J. CARTY.

JUNIOR PAST-PRESIDENTS.

(Term expires July 31, 1916.)
C. O. MAILLOUX.

(Term expires July 31, 1917.)
P. M. LINCOLN.

VICE-PRESIDENTS.

(Term expires July 31, 1916.)
F. S. HUNTING.
N. W. STORER.
FARLEY OSGOOD.

(Term expires July 31, 1917.)
C. A. ADAMS.
J. FRANKLIN STEVENS.
WILLIAM McCLELLAN.

MANAGERS

(Term expires July 31, 1916.)
H. A. LARDNER.
B. A. BEHREND.
P. JUNKERSFELD.
L. T. ROBINSON.

(Term expires July 31, 1917.)
FREDERICK BEDELL.)
BANCROFT GHERARDI.
A. S. McALLISTER.
JOHN H. FINNEY.

(Term expires July 31, 1918.)
C. E. SKINNER.
F. B. JEWETT.
JOHN B. TAYLOR.
HAROLD PENDER.

TREASURER.
GEORGE A. HAMILTON.

(Term expires July 31, 1916.)

SECRETARY.
F. L. HUTCHINSON

HONORARY SECRETARY.
RALPH W. POPE.

LIBRARIAN.
W. P. CUTTER.

GENERAL COUNSEL.
PARKER and AARON,
52 Broadway, New York.

PAST PRESIDENTS.—1884-1915.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-02.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.

*Deceased.

STANDING COMMITTEES

Revised to March 1, 1916

EXECUTIVE COMMITTEE.

J. J. Carty, Chairman,
15 Dey Street, New York.
C. A. Adams, William McClellan,
G. A. Hamilton, Farley Osgood,
A. S. McAllister, J. Franklin Stevens.

FINANCE COMMITTEE.

J. Franklin Stevens, Chairman,
1326 Chestnut Street, Philadelphia, Pa.
Bancroft Gherardi, Farley Osgood.

LIBRARY COMMITTEE.

Samuel Sheldon, Chairman,
198½ Schermerhorn St., Brooklyn, N. Y.
Edward D. Adams, Harold Pender,
F. L. Hutchinson, W. I. Slichter.

MEETINGS AND PAPERS COMMITTEE.

L. T. Robinson, Chairman,
General Electric Company, Schenectady, N. Y.
L. W. Chubb, Secretary,
143 W. Swissvale Ave., Swissvale, Pa.
H. H. Norris, Harris J. Ryan.
Charles P. Steinmetz,
and the chairman of the Technical Committees.

EDITING COMMITTEE.

Henry H. Norris, Chairman,
239 West 39th Street, New York.
M. G. Lloyd, W. S. Rugg,
Harold Pender, W. I. Slichter.

BOARD OF EXAMINERS.

A. S. McAllister, Chairman,
Engineers' Club, 32 West 40th Street, New York.
Philander Betts, F. L. Rhodes
Henry Floy, W. I. Slichter.

SECTIONS COMMITTEE.

H. A. Hornor, Chairman,
Hamilton Court, 39th and Chestnut Streets, Philadelphia, Pa.
Frederick Bedell, J. E. Macdonald,
H. W. Flashman, Charles F. Scott.
and the chairmen of all Institute Sections *ex-officio*.

STANDARDS COMMITTEE.

C. A. Adams, Chairman,
Harvard University, Cambridge, Mass.
Harold Pender, Secretary, Univ. of Pennsylvania, Philadelphia, Pa.
Frederick Bedell, A. E. Kennelly,
L. F. Blume, G. L. Knight,
James Burke, A. S. McAllister,
N. A. Carle, W. M. McConahey,
E. J. Cheney, W. L. Merrill,
Frank P. Cox, R. B. Owens,
W. A. Del Mar, Charles Robbins,
W. F. Durand, L. T. Robinson,
H. W. Fisher, E. B. Rosa,
H. M. Hobart, C. E. Skinner,
F. B. Jewett, H. G. Stott.
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Revised to March 1, 1916

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G. E. Edgar,	O. P. Loomis,
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Revised to March 1, 1916

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U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION.

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Louis Bell,	Clayton H. Sharp,
James Burke,	Samuel Sheldon,
Gano Dunn,	C. E. Skinner,
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John W. Lieb,	H. G. Stott,
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L. L. Edgar, E. A. Wagner,
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Ampere, N. J.
Ralph D. Mershon, Frank J. Sprague.

Term expires July 31, 1917.
A. E. Kennelly, Robert T. Lozier.
S. G. McMeen.

Term expires July 31, 1918.
H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.
Charles F. Brush, William Stanley.
N. W. Storer.

Term expires July 31, 1920.
Carl Hering, Harris J. Ryan,
H. G Stott.

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1916.
C. O. Mailloux, L. T. Robinson,
Farley Osgood.

Term expires July 31, 1917.
B. A. Behrend, Paul M. Lincoln,
William McClellan.

Ex-Officio.

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George A. Hamilton, Treasurer.
F. L. Hutchinson, Secretary.

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The chairman of the Institute's Code Committee.

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ON ADVISORY BOARD, NATIONAL CONSERVATION CONGRESS.
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W. S. Franklin, G. W. Pierce.

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.
Calvert Townley, William McClellan.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.
Charles F. Scott, Samuel Sheldon.

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Percy H. Thomas.

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Paul Winsor.

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Clayton H. Sharp.

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Robert Julian Scott, Christchurch, New Zealand.
T. P. Strickland, N. S. W. Government Railways, Sydney, N. S. W.
L. A. Herdt, McGill Univ., Montreal, Que.
Henry Graftio, Petrograd, Russia.
Richard O. Heinrich, Genest-str. 5, Schoeneberg, Berlin, Germany.
A. S. Garfield, 67 Avenue de Malakoff Paris, France.
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.
John W. Kirkland, Johannesburg, South Africa.

LIST OF SECTIONS

Revised to March 1, 1916.

Name and when Organized		Chairman	Secretary
Atlanta	Jan. 19, '04	A. M. Schoen	H.E. Bussey, Third Nat. Bk. Bldg. Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead	L. M. Potts. Industrial Building, Baltimore, Md.
Boston	Feb. 13, '03	L. L. Elden	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago	1893	W. J. Norton	Taliaferro Milton, 613 Marquette Building, Chicago, Ill.
Cleveland	Sept. 27, '07	E. H. Martindale	Irving H. Van Horn, National Lamp Works, Nela Park, Cleveland, Ohio.
Denver	May 18, '15	W. A. Carter	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor	Jan. 13, '11	Ralph Collamore	C. E. Wise, 427 Ford Bldg., Detroit, Mich.
Fort Wayne	Aug. 14, '08	J. J. Kline	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Ind.
Indianapolis-Lafayette	Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Los Angeles	May 19, '08	E. Woodbury	R. H. Manahan, 32 City Hall, Los Angeles, Cal.
Lynn	Aug. 22, '11	G. N. Chamberlin	F. S. Hall, Gen.Elec.Co.,West Lynn, Mass.
Madison	Jan. 8, '09	M. C. Beebe	F. A. Kartak, Univ. of Wis., Madison, Wis.
Mexico	Dec. 13, '07		
Milwaukee	Feb. 11, '10	R. B. Williamson	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota	Apr. 7, '02	E. T. Street	Walter C. Beckjord, St. Paul Gas Light Co., St. Paul, Minn.
Panama	Oct. 10, '13	William H. Rose	C. W. Markham, Balboa Heights, C. Z.
Philadelphia	Feb. 18, '03	J. H. Tracy	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh	Oct. 13, '02	T. H. Schoepf	G. C. Hecker, 436 Sixth Avenue, Pittsburgh, Pa.
Pittsfield	Mar. 25, '04	M. O. Troy	F. R. Finch, General Electric Company, Pittsfield, Mass.
Portland, Ore.	May 18, '09	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Rochester	Oct. 9, '14	E. L. Wilder	F. E. Haskell, 93 Monica Street Rochester New York.
St. Louis	Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco	Dec. 23, '04	A. H. Babcock	A. G. J nes, 811 Rialto Building, San Francisco, Cal.
Schenectady	Jan. 26, '03	L. T. Robinson	F. W. Peek, Jr., Gen. Elec. Co., Schenectady, N. Y.
Seattle	Jan. 19, '04	C. E. Magnusson	C. F. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Spokane	Feb. 14, '13	Victor H. Greisser	C. A. Lund, Washington Water Power Co., Spokane, Washington.
Toledo	June 3, '07	George E. Kirk	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto	Sept. 30, '03	D. H. McDougall	
Urbana	Nov. 25, '02	P. S. Biegler	T. D. Yensen, Univ. of Illinois, Urbana, Ill.
Vancouver	Aug. 22, '11	R. F. Hayward	H. N. Keifer, Northern Electric Company, Ltd., Vancouver, B. C.
Washington, D. C.	Apr. 9, '03	R. H. Dalgleish	Arthur Dunlop, National Electric Supply Company, Washington, D. C.

Total 32

LIST OF BRANCHES

Name and when Organized		Chairman	Secretary
Agricultural and Mech. College of Texas	Nov. 12, '09	A. Dickie	G. B. Hanson.
Alabama, Univ. of	Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of	Mar. 25, '04	P. X. Rice	F. M. Ellington, University of Arkansas, Fayetteville, Ark.
Armour Institute	Feb. 26, '04	A. A. Oswald	J. F. Hillock, Armour Institute of Technology, Chicago, Ill.
Brooklyn Poly. Inst.	Jan. 14, '16		
Bucknell University	May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of	Feb. 9, '12	J. V. Kimber	H. A. Mulvaney, 1521 Hopkins Street, Berkeley, Cal.
Carnegie Inst. of Tech.	May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of	Apr. 10, '08	W. A. Steward	R. H. Kruse, 75th and Main Streets, Cincinnati, Ohio.
Clarkson Col. of Tech.	Dec. 10, '15	W. A. Dart	C. J. Dresser, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col.	Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College	Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of......Dec. 16, '04	E. F. Peterson	Samuel J. Blythe, University of Colorado, Boulder, Colo.
Georgia School of Technology..............June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College..Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.........June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College.....Apr. 15, '03	F. H. Hollister	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.........May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agric. Col., Manhattan, Kansas.
Kansas, Univ. of.......Mar. 18, '08	E. C. Arnold	E. C. Burke, 1214 Kentucky Street, Lawrence, Kansas.
Kentucky, State Univ. of Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College......Apr. 5, '12	Rodman Fox	Frank H. Schlough, Lafayette College, Easton, Pa.
Lehigh University......Oct. 15, '02	A. F. Hess	R. W. Wiseman, Lehigh University, South Bethlehem, Pa.
Lewis Institute.........Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of........Dec. 26, '06	A. A. Packard	E. V. Crimmin, Univ. of Maine, Orono, Me.
Michigan, Univ. of.....Mar. 25, '04	U. M. Smith	N. F. Brown, University, of Michigan, Ann Arbor, Mich.
Missouri, Univ. of......Jan. 10, '03	K. Atkinson	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col......May 21, '07	Taylor Lescher	J. A. Thaler Montana State College, Bozeman, Mont.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts......Feb. 11, '10	R. V. Davis	R. L. Kelly, West Raleigh, N. C.
North Carolina, Univ. of.Oct 9 '14	P. H. Daggett	
Ohio Northern Univ.....Feb. 9, '12	H. H. Robinson	F. W. Evans, 302 E. Lincoln Avenue, Ada, Ohio.
Ohio State Univ........Dec. 20, '02	R. G. Locket	D. A. Dickey, Ohio State University, Columbus, Ohio.
Oklahoma, Agricultural and Mech. Col..........Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	Clifford O. Oster	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon Agr. Col........Mar. 24, '08	Winfield Eckley	Fred E. Pinn, Oregon Agric. College, Corvallis, Ore.
Penn. State College.....Dec. 20, '02	J. E. Shreffler	Robert P. Meily, Pioneer House, State College, Pa.
Pittsburgh, Univ. of....Feb. 26, '14	G. R. Patterson	W. K. Benz, University of Pittsburgh, Pittsburgh, Pa.
Purdue University......Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Rensselaer Poly. Inst....Nov. 12, '09	W. J. Williams	S. N. Galvin, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst...Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col. Mar. 14, '13	C. E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ..........Dec. 13, '07	A. B. Stuart	H. J. Rathbun, Stanford University, Cal.
Syracuse Univ..........Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of........Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin, Tex.
Throop College of Technology..............Oct. 14, '10	J. W. DuMond	K.W. Rich, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute................Jan. 8, '15	V. Dixon	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of........Feb. 9, '12	W. S. Rodman	J.H. Moore, Dawsons Row, University, Va.
Wash. State Col. of.....Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Coll. of Wash. Pullman, Wash.
Washington Univ.......Feb. 6, '04	P. C. Roberts	Charles A. Lieber, Washington University, St. Louis, Mo.
Washington Univ. of....Dec. 13, '12	E. C. Miller	Geo. S. Smith, Univ. of Washington, Seattle, Wash.
West Virginia Univ.....Nov. 13, '14	H. C. Schramm	C. L. Walker, West Virginia Univ., Morgantown, W. Va.
Worcester Poly, Inst....Mar. 25, '04	R. M. Thackeray	C. C. Whipple, Worcester Polytechnic Institute, Worcester, Mass.
Yale University. ......Oct. 13, '11	P.G. von der Smith	S. R. Large, 343 Elm Street, New Haven, Conn.

Total 54.

American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXV | APRIL, 1916 | Number 4

A. I. E. E. MEETING, APRIL 14, 1916

The 320th meeting of the American Institute of Electrical Engineers will be held in the Engineering Societies Building, 33 West 39th Street, New York, on Friday evening, April 14, at 8:15 p.m.

The subject of the meeting will be Direct-Current Electric Railways, and a paper will be presented by Mr. Clarence Renshaw, of the Westinghouse Electric and Manufacturing Company, entitled *High-Voltage Direct-Current Railway Practise.* The author gives first the fundamental differences in apparatus for 1200 or 1500 volts as compared with the former 600-volt standard, and points out the tendency to reach an ultimate maximum by slight increases in voltage for successive installations. To avoid this multiplicity of voltages it is recommended that a single standard for high-voltage lines be adopted for future installations.

A.I.E.E. WASHINGTON MEETING, APRIL 26, 1916

A meeting of the Institute will be held at Washington, D. C., on Wednesday, April 26, 1916, under the auspices of the Washington Section and the Committee on Development of Water Power.

Headquarters will be at the New Willard, and through the courtesy of the hotel management ample facilities have been put at the Institute's disposal. Two sessions are to be held, the first beginning at 2:30 o'clock in the afternoon, and the second at 8:15 o'clock in the evening, both devoted to the specific question of water power development as related to national industrial efficiency and preparedness.

The appointment by the President of the United States to the Naval Consulting Board of men nominated by the national engineering societies, and the President's subsequent invitation to those societies to cooperate by recommending engineers who should assist in making an inventory of national resources, indicate a broadened field of useful service to our country which engineers as a body can perform.

The forthcoming meeting has been suggested by the Committee on Development of Water Power, which sees a further opportunity for service to the nation by directing the attention of the public and of Congress to the fundamental engineering and economic principles that underly the water power question and which must be taken into account if hydroelectric development is to be encouraged and stimulated, with a corresponding effect on the development of the great electrochemical and similar industries which are essential to the industrial independence of the nation.

At the present time Congress is considering the enactment of legislation intended to remove some of the legal obstructions which in the past have operated to deter capital from investment in hydroelectric enterprises, and it would therefore seem to be a peculiarly opportune moment for the Institute to be of service. As will be noted from

the program which follows, it has been sought to correlate several of those phases of hydroelectric development which are of peculiar and perhaps unusual importance at the present time, while the standing of the authors who have consented to prepare papers insures adequate presentation.

In addition to the ordinary reasons for attendance, members who go to the Washington meeting will be lending their encouragement and support to the effort of those who desire to broaden the Institute's sphere of usefulness and improve its claim to leadership.

The program for this meeting, as at present arranged, is as follows:

1. Address by President John J. Carty.
2. *Electrochemical Industries and Their Interest in the Development of Water Power*, by Lawrence Addicks.
3. *Water Power Development and the Food Problem*, by Allerton S. Cushman.
4. *The Relation of Water Power to Increased Transportation*, by L. B. Stillwell.
5. *The Relation of Water Power to the National Defense*, by W. R. Whitney.
6. *The Water Power Situation, including Its Financial Aspect*, by Gano Dunn.

A. E. S. WASHINGTON MEETING, APRIL 27-29, 1916

The American Electrochemical Society will hold a meeting in Washington, D. C., April 27 to 29, 1916, which immediately follows the A. I. E. E. Washington meeting on Water Power Development, April 26th. Cordial invitations have been extended by each society to attend the other society's meeting. The sessions of the A. E. S. meeting will be as follows:

Thursday morning, business meeting and reading of papers; afternoon, water power development and other papers; evening, lecture by H. J. Pierce on "Water Power Development and Electrochemical Use."

Friday morning, reading of papers; afternoon, steamboat trip to Mount Vernon; evening, reading of papers.

Saturday morning, reading of papers at Bureau of Standards; afternoon, inspection of Bureau of Standards.

The headquarters for the sessions on Thursday and Friday will be the New Willard Hotel. The program includes about 30 technical papers.

A. I. E. E. ANNUAL CONVENTION, JUNE 27-30, 1916

As announced in the March PROCEEDINGS, the Annual Convention of the A. I. E. E. will be held at Cleveland, June 27 to 30. The Convention Committee has designated the Hollenden Hotel as convention headquarters for this convention, and it has appointed various sub-committees as follows:

Automobile Committee; Banquet Committee; Finance Committee; Golf Committee; Ladies Entertainment Committee; Outing Committee; Prize Committee; Publicity Committee; Reception Committee; Tennis Committee.

The personnel of the sub-committees will be announced in the May PROCEEDINGS.

The Meetings and Papers Committee has arranged a tentative program to include six technical sessions. There will be one session devoted to industrial power subjects, one to electrophysics, one to protective apparatus, one to power transmission, and two miscellaneous sessions which will include papers on electric lighting, educational subjects, and telephony and telegraphy.

COMING SECTION MEETINGS

Cleveland.—April 17, 1916, Chamber of Commerce. Paper: "A Modern Direct-Current Substation," by G. B. Scheeberger.

Pittsburgh.—April 11, 1916, Oliver Building. Paper: "Storage Battery

Locomotives and Their Applications," by J. G. Carroll.

Rochester.—April 28, 1916. Paper: "Factory Handling of Direct-Current Motors," by Edward F. Davison and E. Darwin Smith, Jr.

Spokane.—April 21, 1916. Paper: "Transformers—Installation, Operation and Maintenance," by M. W. Birkett.

St. Louis.—April 12, 1916. Paper: "Railroad Day and Night Signals," by B. H. Mann.

May 10, 1916. Paper: "Protection of Buildings Against Lightning," by Terrell Croft.

Vancouver.—April 13, 1916. Paper: "Water Powers of British Columbia," by G. R. G. Conway. Joint meeting with Vancouver Branch Can. Soc. C. E.

REPORT OF COMMITTEE OF TELLERS ON NOMINATION BALLOTS

To the Board of Directors, American Institute of Electrical Engineers:

Gentlemen: This Committee has counted and canvassed, in accordance with Article VI of the Constitution, the nomination ballots received for officers of the Institute for 1916-1917. The result is as follows:

Total number of envelopes said to contain ballots, received from the Secretary		1324
Rejected on account of bearing no identifying name on outer envelope	29	
Rejected on account of having reached Secretary's office after February 29	38	
Envelopes received containing no ballots	20	87
Leaving as valid ballots		1237

These valid ballots were counted and the result is shown below:

FOR PRESIDENT

H. W. Buck	1100
Scattering and blank	137
Total	1237

(The scattering vote was divided among 20 candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR VICE-PRESIDENTS

L. T. Robinson	938
Peter Junkersfeld	866
B. A. Behrend	812
Henry A. Lardner	761
Scattering and blank	324
Total	3701

(The scattering vote was divided among 45 candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR MANAGERS

Walter A. Hall	716
John B. Fisken	692
Charles Robbins	673
E. H. Martindale	633
N. A. Carle	596
Charles S. Ruffner	561
William A. Del Mar	526
Scattering and blank	551
Total	4948

(The scattering vote was divided among 40 candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR TREASURER

George A. Hamilton	1076
Scattering and blank	161
Total	1237

Respectfully submitted,

FREDERICK BORCH, *chairman.*
WM. A. MOORE,
RALPH S. RANKIN,
RICHARD MAETZEL,
R. H. CARPENTER,
Committee of Tellers.

MILITARY TRAINING IN CIVIL EDUCATIONAL INSTITUTIONS

The following document has been submitted for publication in the PROCEEDINGS.

It is not within the scope of the Institute to take a partisan position with respect to public matters of this kind, but the letter is given as of general interest to engineers.

New York, February 17, 1916.

To the members of the
American Society of Civil Engineers,
American Institute of Mining Engineers
American Society of Mechanical Engineers,

American Institute of Electrical Engineers,
American Institute of Consulting Engineers.

Gentlemen:

Identical Bills have been introduced into the United States Senate and House of Representatives providing for the extension of the military training now given in land-grant colleges and some other civil educational institutions, and for the establishment of military instruction in such additional institutions as elect to come under the provisions of the Bills. The prime object of the proposed legislation is that of building up a reserve of trained officers available for officering volunteer forces in case of war. In the opinion of the undersigned the plan of the proposed legislation will accomplish this, and at a minimum cost to the nation; and will, at the same time, provide an element of discipline and training of great value in the civil life both of the individuals undergoing it and of the community.

[Enclosed with the letter mailed to individuals was a brief statement of the principal points covered by the Bills, together with an answered questionnaire covering such points of information as would be desired by one giving the subject careful consideration.]

The plan contemplated does not in any way conflict with any of the other plans proposed in the interest of preparedness. On the contrary, it will supplement and fit in with any other plan which may be adopted, whether it involves training camps, a reserve officers training corps, a reserve officers corps, etc., or any or all of these. The undersigned earnestly request that the members of the various national engineering societies send personal letters or telegrams to their individual Senators and Representatives worded somewhat as follows:

I urgently request you to support and vote for the plan covered by Bill S-3946 introduced by Senator Pomerene, and H. R. 10845 introduced by Representative Gard, providing for the extension of military training in civil educational institutions.

In making this request we are acting as individuals, and not as the official representatives of the societies. Each of us is, however, a member of one or more of the societies addressed, and we urge prompt action of our fellow members in the societies to which we respectively belong. It is your individual action that we particularly ask in this matter. In addition to your individual letters and telegrams to your Senators and Representatives, it is desirable that you write any other members of Congress whom you may be able to influence, and that you induce as many other persons as possible to take similar action.

Time is the essence of this matter. We earnestly request that you act promptly.

Very truly yours,

Bion J. Arnold	Ralph D. Mershon
John A. Brashear	Wm. B. Parsons
E. L. Corthell	M. I. Pupin
J. J. Carty	Charles F. Rand
W. F. Durand	Jno. F. Stevens
W. F. M. Goss	Geo. F. Swain
Alex.C.Humphreys	Ambrose Swasey
A. M. Hunt	L. B. Stillwell
E. C. Jones	W. H. Wiley
W. S. Lee	W. J. Wilgus

NOTE: As an indication of the effectiveness of this appeal, it will be helpful to those responsible for it if after acting upon it you will send a brief statement of the extent to which you have done so to Ralph D. Mershon, 80 Maiden Lane, New York City.

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS—A CENTER OF COOPERATION

BY DUGALD C. JACKSON

The American Institute of Electrical Engineers serves the purpose of giving cooperative association to the professional work of electrical engineers. This is important because no professional man in this age can do constructive work for himself alone. Cooperation and interchange of knowledge with others is a necessary part of professional life. The conditions of the old time, one-man service, have passed away—probably forever. However high up a man may now go, he must cooperate cordially and loyally with his associates, and they must cooperate with him; and through the American Institute of Electrical Engineers the various men in our branch of the engineering profession have the opportunity to become acquainted with each other, to know and appreciate the work of their professional rivals and associates, and to enlarge and improve

the cooperation between man and man and between groups of the profession.

Even those great inventions in our profession that came from the dreams of individuals were soon expanded beyond the thought of any one man. None has sprung developed in full completeness and in widest application from the thought of its creator, like Minerva in full panoply from the brow of Jove; and it has in fact taken groups composed of numerous men working cooperatively to a single coordinated end to bring each great invention to its full fruition. The telephone, for instance, is essentially the result of the dreams of Alexander Graham Bell, but as we know the telephone structure thirty years after the telephone's birth, serving as it does for communication from edge to edge of continents, and knitting into neighborship our hundred million people, the structure is a coordinated result of loyal cooperative work by hundreds of inventors, investigators, designers, and other engineers. Many have prosecuted their work apart from others, but the results have cooperated because of the common end and the common knowledge equally spread before all. Thus, also, the multiple-unit train control which sprang from the inspiration of Frank Julian Sprague, and was put by him almost single-handedly into its original use, has become a perfected appliance (used world-wide where rapid transit is found in cities) through the efforts of many additional inventors, investigators, designers and other engineers who have cooperated in improving and magnifying the usefulness of Mr. Sprague's original thought.

This condition in no wise detracts from the great reputations of the eminent men who have made original conceptions, and it indeed enhances their usefulness to the world by enlarging and widening the serviceableness of their inventions. Through the American Institute of Electrical Engineers, all men who are thus engaged in advancing the arts mentioned in the foregoing illustrations and also those engaged in all of the various other branches of the arts into which electrical engineering is divided, are kept in relationship with each other by means of its meetings and its TRANSACTIONS.

The historian Macauley cogently says: "Of all inventions, the alphabet and the printing press alone excepted, those inventions which abridge distance have done most for the civilization of our species." It is of interest to us, as electrical engineers, to notice that certain of the inventions like the telegraph, the telephone, the electric distribution of power, and, now in growing degree, the electric railway, which have had a large part in abridging distance within nations and between nations, are peculiarly within the province of electrical engineering. As electrical engineers, we may take great pride in their serviceableness to civilized peoples. We can remember with equal pride that their rapid spread in serviceableness is partly due to the sincere cooperation of electrical engineers in making these influences socially useful, and that this unit of effort has been and is fostered by the personal associations which arise through societies like our own and through the publication and circulation of their Transactions.

This is an altruistic aspect of our Institute, but I also say with complete sincerity that every electrical engineer of ambition can find a serviceable personal stimulus from membership in the Institute through attendance at its meetings, participation in its papers and discussions, and reading its TRANSACTIONS. In order to make the most of these opportunities, a reasonable ambition should lead the young men in the profession not only to membership in the lower grades of the Institute ranks, but also to desire transfer to the higher grades as soon as their professional experience and responsibilities warrant.

UNITED ENGINEERING SOCIETY, CONDENSED FINANCIAL STATEMENT FOR THE YEAR 1915

To the Board of Trustees
United Engineering Society:

I respectfully submit the following report of your Treasurer for the year ending December 31, 1915.

Finances

Due to the growth of the activities of the United Engineering Society, it was found desirable early in the year to consolidate the various accounts and financial records of the Society and of the Library, heretofore kept separately, and to have all the data pertaining to the building and its operation in the charge of one individual. An assistant secretary especially assigned to this work has been appointed, and a separate office has been established. The Finance Committee has had all of the records brought fully to date and has prepared a new set of account books to meet the new conditions.

The Real Estate Account now includes the following items:

Land	$540,000.00
Building	1,050,000.00
Equipment	33,171.16
Founder Societies, Preliminary expenses	24,000.00
Total	$1,647,171.16

The principal of the mortgage on the land held by Andrew Carnegie amounting originally to $540,000 has been finally satisfied in full by payments from the Land and Building Funds by the Founder Societies. These payments were $5,000 from the American Institute of Mining Engineers, in January, and $54,000 from the American Institute of Electrical Engineers, in June.

The gross Operating Expenses for the year 1915 were $44,440.28, an increase of $4,858.64 over the gross expenses of the preceding year. This increase was due chiefly to the unusual alterations on the sixth floor amounting to $4,258,36.

The total revenue for the year was $48,028.20.

The funds available for the uses of the Library Board during the year were $17,444.87. The expenditures of the Library Board were $16,415.14, leaving an unexpended balance of $1,029.73.

The "General Reserve Fund" of $10,000 created by the Board of Trustees at a meeting held November 19, 1914, to be available to take care of unforeseen fluctuations of income and outlay, has been preserved intact, there arising no calls on this fund during the year 1915.

At the beginning of the year 1915 the amount of Contingency and Renewal Fund was $51,441.39. To this amount has been added the sum of $2,404.28 for interest earned by the investments for this fund during the year, and $5,000 added from surplus at the end of the year, bringing the total at the end of the year to $58,845.67.

The following summary shows the Reserve Accounts:

Depreciation and Renewal Fund	$51,441.39
Add: Interest on Invested Funds during Year 1915	2,404.28
Transfer for the Year 1915	5,000.00
	$58,845.67
General Reserve Fund	$10,000.00
Engineering Foundation Fund	200,000.00
Library Endowment Fund	5,000.00
	$273,845.67

The Astor Trust Company of New York is the official custodian of the securities of the United Engineering Society.

During the year the Finance Committee with the assistance of experts has revised the assessments for space occupied by all Societies, Founders as well as Associates. In doing this, consideration has been given to location as well as area occupied, and the system of assessment made uniform. The schedule of rates is available for examination by any interested person or society.

Gifts and Endowments

On January 27, 1915, Mr. Ambrose Swasey presented to the United En-

gineering Society the sum of $200,000 in securities, the income only therefrom to be used for the purposes of the Engineering Foundation, for "the advance of the engineering profession and the benefit of mankind."

On April 5, 1915, Dr. James Douglas presented the sum of $5,000 to the United Engineering Society to form the nucleus of an Endowment Fund for the Library.

Meetings or Lectures

The record of the number of times the rooms were used during the year (1915) for meetings or lectures (not for office occupancy) is shown in the accompanying table.

Meeting Room	Number of times occupied		
	1914	1915	Change
1st floor foyer	0	1	1 more
Auditorium 3rd and 4th floors	76	42	34 less
No. 1 Assembly Room 5th floor	58	53	5 "
" 2 " " 5th "	94	76	18 "
" 3 " " 5th "	46	49	3 more
" 5 " " 6th "	0	2	2 "
Small committee room on 1st "	18	34	16 "
Assembly room 1201 on 12th "	53	30	23 less
Total	345	287	58 less

Library

During the year the administration of the Library has been made the subject of an agreement executed by the three Founder Societies and the United Engineering Society under which all expenses of the Library are paid from the United Engineering Society office. Each Founder Society has contributed $4,000 and the remainder of $2,500 has been paid by the United Engineering Society. The total appropriation for books and administration amounted to $14,500 for the year. In addition there were derived from searches, $2,410.80, and from sales and income $534.07, making a total revenue of $17,444.87.

In June there was effected a consolidation of the various insurance policies heretofore held separately by the Founder Societies and the United Engineering Society, into one policy covering all.

Full details as to the Library are shown in the annual report of the Library Board. (See abstract, page 28, February 1916 Proceedings.)

Respectfully submitted,

Joseph Struthers,
Treasurer.

UNITED ENGINEERING SOCIETY
Statement of Assets and Liabilities
December 31, 1915.

Assets:

Real Estate	$1,647,171.16
Investments—Engineering Foundation Fund	200,000.00
" Library Endowment Fund	5,002.50
" —General Funds	58,138.75
Cash	11,307.05
Unexpired insurance	3,949.16
Accounts receivable	3,785.36
	$1,929,353.98

LIABILITIES:

Founders Equity in Property	$1,647,171.16
Due the General Reserve Fund	10,000.00
Due the Depreciation and Renewal Fund	58,845.67
Due the Engineering Foundation Fund	200,000.00
Due the Library Endowment Fund	5,000.00
Due the Library Board—1915 unexpended balance	1,029.73
Surplus Dec. 31, 1915	7,307.42
	$1,929,353.98

Audited and found correct Jan. 27, 1916.
BARROW, WADE, GUTHRIE & CO.

Correct, CHAS. F. RAND, *Chairman*,
H. H. BARNES, JR.,
JESSE M. SMITH.
Finance Committee.

A. I. E. E. MEETING IN NEW YORK, MARCH 10, 1916

The 319th meeting of the American Institute of Electrical Engineers was held in the Engineering Societies Building, New York, on Friday, March 10, 1916. This was a joint meeting with the New York Section of the American Electrochemical Society.

President John J. Carty of the Institute called the meeting to order at 8:30 p.m., and requested Mr. Colin G. Fink, chairman of the New York Section of the American Electrochemical Society, to preside when the paper from his society was being read.

The A. I. E. E. paper, entitled *The Influence of Frequency of Alternating or Infrequently Reversed Current on Electrolytic Corrosion*, by Messrs. Burton McCollum of the United States Bureau of Standards and G. H. Ahlborn of the Ohio Electric Railway Company, was presented by Mr. McCollum, and discussed by Messrs. Philip Torchio, Alexander Maxwell, Albert F. Ganz, J. L. R. Hayden, S. M. Kintner, Carl Hering, Asa P. Way, C. B. Martin, Thomas M. Roberts, L. W. Chubb, and Thomas Spooner.

Mr. Colin G. Fink then took the chair, and called for the presentation of the A. E. S. paper, entitled "Electrolytic Corrosion of Metals," by Professor William H. Walker of the Massachusetts Institute of Technology. Professor Walker was unable to attend the meeting, and the paper was presented by Dr. William K. Lewis, who exhibited some samples of corroded iron and other metals. Those who took part in the discussion were Messrs. A. S. Cushman, Maximilian Toch, H. F. Speller, and James Aston.

DIRECTORS' MEETING, NEW YORK, MARCH 10, 1916

The regular monthly meeting of the Board of Directors was held at Institute headquarters in New York on Friday, March 10, 1916, at 3:30 p.m.

There were present: President John J. Carty, New York; Past-President C. O. Mailloux, New York; Vice-Presidents F. S. Hunting, Fort Wayne, Ind., Farley Osgood, Newark, N. J., C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., and William McClellan, New York; Managers H. A. Lardner, New York, B. A. Behrend, Boston, Mass., P. Junkersfeld, Chicago, Ill., L. T. Robinson, Schenectady, N. Y., Bancroft Gherardi, New York, A. S. McAllister, New York, C. E. Skinner, Pittsburgh, Pa., John B. Taylor, Schenectady, N. Y., and Harold Pender, Philadelphia, Pa.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $10,933.48 was ratified.

The Midwinter Convention Entertainment Committee reported that the receipts from the sale of tickets to

the dinner-dance held during the mid-winter convention exceeded the expenditures by $148.11, and recommended that the surplus be held as a fund to be available for future mid-winter convention social functions. With the concurrence of the Finance Committee this recommendation was approved.

The Board adopted the following resolution thanking the committee:

Resolved, that the Board of Directors of the American Institute of Electrical Engineers hereby expresses, to the Midwinter Convention Entertainment Committee, its hearty appreciation of the committee's management of the Dinner-Dance on February 9, and of the pronounced social and financial success of this enjoyable event.

The report of the Board of Examiners of its meeting held on March 2 was read and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners, 70 applicants were elected as Associates, five as Members, and two Associates were transferred to the grade of Member. Seventy-six students were ordered enrolled.

Upon invitation of the Executive Committee of the National Conservation Congress, the president was authorized to appoint five representatives to attend the forthcoming congress, which is to be held in Washington, D. C., May 2-4, 1916.

The death on February 13, 1916, of Dr. Louis Duncan, who was president of the Institute for two terms from 1895 to 1897, and who had always maintained an active interest in its affairs, was announced by the secretary, and resolutions were adopted as a tribute to his memory.

The report of the Committee of Tellers of its canvass of the nomination ballots cast for candidates for the Institute offices falling vacant on July 31, 1916, was read. The Board then selected by ballot its list of Directors' Nominees, in accordance with Section 31 of the constitution, with the following result: For President, H. W. Buck, New York; for Vice-Presidents, L. T. Robinson, Schenectady, N. Y., Peter Junkersfeld, Chicago, B. A. Behrend, Boston, Mass., Henry A. Lardner, New York; for Managers, John B. Fisken, Spokane, Wash., Charles Robbins, Pittsburgh, Pa., N. A. Carle, Newark, N. J., Charles S. Ruffner, St. Louis, Mo.; for Treasurer, George A. Hamilton, Elizabeth, N. J.

It will be noted that the Board of Directors placed upon the list of Directors' Nominees the names of four candidates for the office of vice-president, three of whom are to be elected.

PAST SECTION MEETINGS

Baltimore.—February 11, 1916, Physical Laboratory, Johns Hopkins University. Paper: "Physical Aspects of Radiotelegraphy," by John L. Hogan, Jr. Attendance 46.

Chicago.—February 28, 1916. Subject: Street Illumination. Papers: (1) "Recent Street Lighting Problems and Developments," by J. R. Cravath; (2) "Some Experiences and Tests in Connection with Chicago Street Lighting," by A. C. King; (3) "Street Lighting Plans of Milwaukee," by F. A. Vaughn. Attendance 80.

Cleveland.—February 18, 1916, Hof Brau. Paper: "Daylight and Twilight Illumination," by H. H. Kimball. Attendance 50.

Detroit-Ann Arbor.—January 28, 1916, Detroit Engineering Society Hall. Paper: "Some Problems in A-C. Street Series Lighting, and Their Solution," by E. J. Edwards. Attendance 30.

February 11, 1916, Detroit Engineering Society Hall. Paper: "1915 Electric Code and Changes," by Ernest McCleary. Attendance 100.

Denver.—February 19, 1916. Paper: "The Future of Water Power in the United States," by Charles W. Comstock. Attendance 32.

Indianapolis-Lafayette. — February 25, 1916. Paper: "Electricity, Its

Application and Use," by William Allen Moore. Attendance 75.

Ithaca.—February 18, 1916, Franklin Hall, Cornell University. Illustrated lecture by Mr. Scott Lynn on "Applications of the Ampere-Hour Meter." Attendance 60.

March 3, 1916, Franklin Hall, Cornell University. Debate: "Appeal in the Lighting Controversy between the City of Colorado Springs and Pike's Peak Electric Company." Decision in favor of men for the company. Attendance 55.

Los Angeles.—February 23, 1916, Chamber of Commerce. Paper: "The Panama Canal and Its Electrification," by E. E. Valk. Attendance 51.

Lynn.—February 7, 1916, Center Street, Lynn. Lecture on "Ore Milling Oil Methods in Alaska," by Howard W. DuBois. After the lecture complete laboratory equipment was set up and Mr. DuBois performed experiments illustrating the extraction of metal. Colored lantern slides of Alaska scenes were shown. Attendance 250.

February 16, 1916, Lynn Classical High School. Lecture by Mr. Walter D'Arcy Ryan on "Illumination at the Panama-Pacific Exposition." Lecture was illustrated by colored lantern slides. Attendance 750.

March 1, 1916, General Electric Works, West Lynn. Illustrated lecture by Mr. Richard H. Rice on "Lines of Progress in Turbine Engineering." Attendance 280.

Madison.—January 12, 1916, Library, Engineering Building, University of Wisconsin. Addresses as follows: (1) "Features of the Transcontinental Telephone Lines," by H. O. Seymour; (2) "Properties of Loaded and Unloaded Telephone Lines," by Edward Bennett. Following the addresses, telephonic communication was established between Madison and the Pacific Coast, receivers being supplied for all present. Attendance 130.

Milwaukee.—March 8, 1916, Republican House. Illustrated address by Ensign J. L. Riheldaffer on "Our Navy." Attendance 85.

Minnesota.—February 24, 1916, Engineering Building. University of Minnesota. Papers: (1) "Excitation of Synchronous Machines," by Theodor Schow; (2) "Electric Starting Equipment for Automobiles," by T. H. Edwards. Attendance 35.

Panama.—February 21, 1916, University Club, Panama. Annual Banquet of Panama Section. Attendance 61.

Pittsburgh.—February 8, 1916, Engineering Society of Western Pennsylvania Rooms. Paper: "Latest Theories of Magnetism," by Saul Dushman. Attendance 133.

Pittsfield.—March 2, 1916, Hotel Wendell. Address by Dr. M. I. Pupin on "Radio Telegraphy and Telephony." Attendance 97.

Rochester. — February 25, 1916, Rochester Engineering Society Rooms. Paper: "Electrolysis," by A. B. Herrick. Paper was illustrated by lantern slides, and demonstration of actual apparatus was given. Attendance 39.

San Francisco.—February 25, 1916, Engineers Club. Paper: "Some Features in Connection with the Installation of Two Submarine Power Cables across the Golden Gate," by S. J. Lisberger. Attendance 80.

Schenectady.—February 23, 1916, Edison Club Hall. Paper: "The Regulation of Public Utilities," by Edward J. Cheney. Attendance 100.

March 7, 1916, Edison Club Hall. Paper: *Iron Losses in Direct-Current Machines*, by B. G. Lamme. Attendance 300.

Seattle.—February 15, 1916, Central Building. Paper: "Electric Vehicles," by A. S. Garrison. Paper illustrated by lantern slides. Attendance 30.

Spokane.—February 18, 1916, Stone Room, Spokane Hotel. Paper: "Maintenance of Telephone Plant," by G. H. Benson. Attendance 33.

St. Louis.—March 8, 1916, Engineers Club. Illustrated address by Mr. A. W. Hitchcock on "Safety and the Human Element at Hawthorne." Attendance 54.

Toledo.—February 16, 1916, Toledo Commerce Club. Illustrated lecture by Mr. Geo. Housdorfer on "The 2000-kw. Turbine at the Water Street Station." Following the lecture the assembly took a trip to the power house to inspect the equipment. Attendance 42.

March 8, 1916, Toledo Commerce Club. Messrs. T. J. Nolan, W. W. Hansen and Emil Grah spoke on their experiences in the early days of electrical development. Election of officers as follows—chairman, W. E. Richards; vice-chairman and program committee, G. E. Kirk; membership committee, M. E. Grah; secretary and treasurer, Max Neuber; executive committee, O. F. Rabbe. Attendance 30.

Urbana.—February 25, 1916. Paper: "Ratemaking as Applied to Electric Light and Power," by W. A. Gatward. Attendance 50.

PAST BRANCH MEETINGS

University of Arkansas.—January 25, 1916. Papers: (1) "History of the Steam Engine;" (2) "Lubrication;" (3) "Sparks." Attendance 24.

February 9, 1916. Papers: (1) "Home Electric;" (2) "Back to the Farm." Attendance 55.

February 16, 1916. Debate—Resolved, that electric drive is to be installed in industrial plants and is superior to mechanical drive. Attendance 25.

Armour Institute.—February 24, 1916. Chapin Hall. Paper: "Rates." Attendance 6.

Brooklyn Polytechnic Institute.—February 28, 1916, Mailloux Library of Electrical Engineering. Election of officers as follows—chairman, Albert H. Bernhard; first vice-chairman, Henry J. Goss; second vice-chairman, Edward W. Tree; secretary, Walter J. Seeley; treasurer, J. Van Rensselaer. Attendance 20.

Bucknell University.—February 21, 1916, Chemical Laboratory. Address by Mr. Edwin C. Hagemann on "Edison and the Development of Electric Lighting." Attendance 32.

University of California.—February 16, 1916. Addresses by Messrs. Partsch and Murray on "Electric Railroad Problems." Attendance 24.

Carnegie Institute of Technology.—February 17, 1916, Machinery Hall. Papers: (1) "Equipment and Operating Features of Brunot's Island Power Plant," by E. C. Stone; (2) "Description of Prime Movers of Brunot's Island Power Plant," by J. C. Hobbs. Attendance 22.

Clarkson College of Technology.—February 16, 1916. (1) "Physical Characteristics of Dielectrics," by A. P. M. Fleming; (2) "Chattering Wheel Slip in Electric Motive Power," by G. M. Eaton. Attendance 8.

March 8, 1916. Paper: "Iron Losses in Direct-Current Machines," by B. G. Lamme, reviewed by Prof. A. R. Powers. Attendance 22.

University of Colorado.—February 24, 1916, Physics Lecture Room. Address by Mr. Paul Gaylord on "Hydraulic Power Development in the United States." Attendance 25.

Colorado State Agricultural College.—March 8, 1916, Electrical Building. Address on "Rail Bonds, Their Application, Use, Testing and Repair." Attendance 9.

Georgia School of Technology.—February 17, 1916, Physics Lecture Room. Address by Dr. J. S. Coon on "Engineering Projects in Florida and Cuba." Attendance 30.

Highland Park College.—March 1, 1916, Electrical Laboratory. Address by Prof. Lemnax on "Electric Lighting and Cranking of the Automobile." Attendance 49.

Iowa State College.—February 16, 1916. Paper: "Concentric Wiring," by H. B. Alden. Attendance 26.

March 3, 1916. Paper: "Modern

Attack on the Lighting Problem," by Dr. E. P. Hyde. Attendance 110.

University of Iowa.—February 29, 1916, Physics Building. Paper: "The Selenium Cell," by F. C. Brown. Attendance 21.

Kansas University.—February 23, 1916, Chemistry Building. Address by Prof. H. P. Cady on "Liquid Air." Address was illustrated with many interesting experiments. Attendance 51.

March 1, 1916. Annual "Electrical Day." Banquet was held in the evening at which 72 were present.

Kansas State Agricultural College.—February 24, 1916, Engineering Amphitheatre. Papers: (1) "Some New Developments in 1915," by W. C. Ernsting; (2) "Some Thesis Work of the 1916 Class," by Andrew Herold. Attendance 26.

State University of Kentucky. February 24, 1916, Mechanical Hall. Papers: (1) "Chattering Wheel Slip in Electric Motive Power;" (2) "True Nature of Speech;" (3) "The Liquid Rheostat in Locomotive Service." Attendance 22.

Lehigh University.—February 25, 1916. Address by Mr. C. R. Underhill on "Electromagnets." Mr. A. F. Hess gave an account of the senior electrical inspection tour. Attendance 55.

Lewis Institute.—February 2, 1916. Illustrated address by Mr. H. N. Foster on "Modern Seven League Boots." Attendance 425.

University of Maine.—March 7, 1916. Lord Hall. Demonstration of electrical phenomena by Mr. A. L. Davis. Attendance 20.

University of Missouri.—January 10, 1916, Engineering Building. Paper: "Tallulah Falls Development." Attendance 20.

February 14, 1916. Paper: "Electric Furnaces in the Iron and Steel Industry." Attendance 26.

February 28, 1916. Paper: "Wireless." Attendance 23.

North Carolina College of Agricultural and Mechanical Arts. February 16, 1916. Addresses as follows: "The Production of Aluminum at Whitney, N. C.," by D. A. Monroe; "House Wiring Problems," by P. E. Snead. Attendance 23.

February 23, 1916. Papers: (1) "Electric Automobile Brake;" (2) "Opportunities for Young Electrical Engineers." Attendance 21.

February 28, 1916. Illustrated lecture on "The Development of Hydraulic Power," by R. V. Davis and P. E. Snead. Attendance 50.

Ohio Northern University.—February 23, 1916, Dukes Memorial. Addresses as follows: "Self-Contained Portable Electric Mine Lamps," by Mr. McKee; "Manufacture of Shrapnel," by Prof. Thornburg. Attendance 22.

Ohio State University.—March 10, 1916, Auditorium, Robinson Laboratory. Lecture by Mr. J. C. Lincoln on "Floating Bodies Heavier than Water by Electrical Means."

Oregon Agricultural College.—February 25, 1916. Discussion on "Electric Railroads." Attendance 25.

University of Pittsburgh.—February 9, 1916. Paper: "Electrolysis by Stray Currents," by C. O. Franklin. Attendance 19.

February 23, 1916. Paper: "Corona Losses," by H. J. Dible.

Purdue University.—February 11, 1916, Electrical Building. Paper: "The Manufacture and Testing of High-Tension Insulators," by E. R. Snyder. Attendance 55.

Rose Polytechnic.—February 17, 1916. Paper: "The Tesla Coil, and Experiments with Very High Potentials," by C. C. Knipmeyer. Attendance 35.

Stanford University.—February 8, 1916. Paper: "Substation and Equipment of the Cincinnati, Hamilton and Dayton Dock at Toledo, Ohio," by A. B. Stuart. Attendance 20.

February 15, 1916. Paper: "The

Automatic Telephone," by C. F. Williams. Attendance 19.

February 29, 1916. Address by Prof. H. J. Ryan on "High-Voltage Transmission Towers and Cables Installed at the High-Tension Laboratory." Illustrated address by Mr. W.B. Burbeck on "Engineering Achievements of the Pacific Gas and Electric Company." Attendance 24.

Syracuse University.—February 7, 1916. Address by Mr. G. Douglas Wardrop on "Air Craft in Warfare." Attendance 195.

February 15, 1916. Paper: "Water Power Development," by W. R. Dwyer. Attendance 40.

February 24, 1916. Paper: "Electron Measurements," by F. B. Kuiskern. Attendance 14.

March 2, 1916. Paper: "Copper Mining," by M. C. Mellinger. Attendance 12.

University of Texas.—February 11, 1916. Papers: (1) "Historical Sketch of the Development of Electrical Transportation;" (2) "Block Signals;" (3) "Comparison of A-C. and D-C. Systems of Electrification of Steam Roads;" (4) "Location of Right of Way." Attendance 13.

Virginia Polytechnic Institute.—February 25, 1916. Illustrated lecture by Mr. John W. Crowley on "The Application of Electric Power to Various Machines." Attendance 147.

University of Virginia.—February 16, 1916, Mechanical Laboratory. Papers: (1) "Wireless Telegraphy," by T. R. Bunting; (2) "Electromagnetic Transmission," by R. C. Harrison. Attendance 25.

March 1, 1916. Papers: (1) "Automatic Disk and Needle Changing Device for Talking Machines," by J. L. Rorison; (2) "Power Plant of the Boat *Down*," by G. M. Garmany; (3) "Philadelphia-Paoli Electrification," by J. H. Moore. Attendance 32.

Washington University.—March 9, 1916. Paper: "Modern Illuminants," by Prof. H. G. Hake. Attendance 20.

Worcester Polytechnic Institute.—February 18, 1916, Lecture Hall, Electrical Engineering Building. Lecture by Mr. C. R. Underhill on "Electromagnets." Attendance 45.

Yale University.—March 3, 1916, Electrical Engineering Laboratory. Paper: "Industrial Electric Power," by Courtland W. Babcock. Attendance 70.

PERSONAL

MR. DANIEL W. MEAD and MR. F. W. SCHEIDENHELM announce their association in the practise of engineering, with offices in the Equitable Building, 120 Broadway, New York. They will continue to give their attention to reports, designs and construction, covering hydraulic and electric developments, water supply and reclamation works.

MR. GEORGE KINGDON PARSONS, consulting engineer, announces the location of his main offices in the Equitable Building, New York, in addition to his location in the Riggs Building, Washington, D. C., for his practise in industrial counsel, investigations, designs, management, valuations, etc., and expert testimony and patent cases in consultation with legal counsel.

MR. H. C. EDDY, who recently resigned as engineer for the Public Utilities Commission of the District of Columbia, has received a temporary appointment with the Navy Department and is now located at the Naval Proving Ground, Indian Head, Md., supervising the enlargement of the power station and the installation of several additional boilers, coal conveyer, etc., and remodeling the present boiler plant.

MR. FRANK T. WYMAN has severed his connection as chief engineer of the Pittsburgh Transformer Company to accept the position of chief engineer of the Packard Electric Company of St. Catharines, Ontario. Mr. Wyman has been connected with the Pittsburgh

Transformer Company for the past seven years, following four years of teaching electrical engineering in Drexel Institute, Philadelphia, and the University of Pittsburgh.

MR. W. E. SKINNER, consulting engineer, has opened an office at 415 Plymouth Building, Minneapolis, Minn. Until recently Mr. Skinner was president and manager, W. E. Skinner, Ltd., consulting engineers, Winnipeg, Manitoba. Prior to entering the consulting field in Winnipeg in 1907 Mr. Skinner was connected with the Westinghouse interests in Pittsburgh, Buffalo, Honolulu, Hawaii, Hamilton, Ontario, and Winnipeg. In addition to the engineering work he has handled for numerous corporations, cities, and towns he has also acted in a consulting capacity for two years for the Public Utilities Commissioner of Manitoba.

OBITUARY

HENRY WILLIAM POPE, brother of Honorary Secretary Ralph W. Pope and of the late Past-President Franklin L. Pope, died at Bellerose, Long Island, N. Y., February 29, 1916, at the age of sixty-eight. Mr. Pope was born in Great Barrington, Mass., November 2, 1848. He succeeded his brothers as manager of the telegraph office at that place at the age of 14. In 1863 he was transferred to the main office of the American Telegraph Company in New York. After service as an operator in Boston, Mr. Pope became in 1872 chief operator of the Gold and Stock Telegraph Company and in the following year assistant general superintendent of the American District Telegraph Company in New York. From 1876 to 1879 he was general superintendent of the company, and introduced the first telephone ever installed for commercial purposes in New York, the first adaptation of the simultaneous telephone and telegraph principle, and improvised and constructed in 1877 the first telephone hook switch, installed in the office of the Roosevelt organ factory in Eighteenth Street. From 1879 to 1882 Mr. Pope was general superintendent of the New York Bell Telephone Company, and one of the appraisers of the telephone property in New York City, prior to the consolidation of the telephone interests. He organized the first telephone convention, at Niagara Falls. In 1883 he organized the Mutual District Messenger Company of New York. Mr. Pope then engaged in the organizing and constructing of a large number of street railway and electric light plants in different cities, notably the Citizens' Electric Illuminating Company of Brooklyn, of which he was president—the first company to introduce electric lights in the city of Brooklyn. In 1895 he again identified himself with the telephone interests, serving in various official capacities with the American Telephone and Telegraph Company and the Southern Bell Telephone and Telegraph Company. In 1900 he was appointed acting general manager of the Bell Telephone Company of Buffalo, operating the territory in the western part of the State of New York. In 1904 he became a special agent of the American Telephone and Telegraph Company, New York. It was the opinion among telephone men that Mr. Pope had probably done more than any other one telephone official in America to advance the popularity of the telephone with the public at large and with business men. Mr. Pope was the organizer of the Telephone Pioneers of America. He was elected an Associate of the Institute March 23, 1898.

JOHN CHARLES MANLEY, assistant construction superintendent of the Commonwealth Edison Company, of Chicago, died March 17, 1916, of heart failure. He had been associated with the Commonwealth Edison Company since 1895, when he started in as a wireman in the station construction department. In 1906 Mr. Manley was made assistant construction superintendent of the company. Three years ago, when

the city of Dayton, Ohio, was devastated by floods, Mr. Manley took a picked crew there from Chicago and worked day and night to rehabilitate the central station system, and it was largely due to his efforts that the remarkably quick recovery was made. He was of an inventive turn of mind, and several improvements in the art of wiring are attributed to him. Mr. Manley was elected an Associate of the Institute April 26, 1907.

RECOMMENDED FOR TRANSFER, MARCH 2, 1916

The Board of Examiners, at its regular monthly meeting on March 2, 1916, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To the Grade of Fellow

Foster, William F., Designing Engineer, General Electric Co., Schenectady, N. Y.

To the Grade of Member

Atkins, David Fowler, Chief Engineer, Bureau of Gas and Electricity, Department of Water Supply, Gas and Electricity, New York, N. Y.

Cook, Thomas R., Chief Engineer, Willard Storage Battery Co., Cleveland, Ohio.

TRANSFERRED TO THE GRADE OF MEMBER MARCH 10, 1916

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on March 10, 1916.

Carroll, John Gustave, Electrical Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Kerr, William C., Construction Engineer, Philadelphia Rapid Transit Co., Philadelphia, Pa.

MEMBERS ELECTED MARCH 10, 1916

Bailey, Thaddeus Francis, President, Electric Furnace Co., Alliance, Ohio.

Barter, Harold Hendryx, Director of Works, Panama-California Exposition; res., 401 Olive St., San Diego, Cal.

Borden, Stephen Whiley, General Manager, Electrical Properties of Commonwealth Water and Light Co.; res., 30 Beauvoir Ave., Summit, N. J.

Crouse, John L., Superintendent of Electric Shops, N. Y., N. H. & H. R. R. Co., Van Nest, N. Y.

Hight, Eugene Stuart, Electrical Engineer, Illinois Traction System, Mayer Building, Peoria, Ill.

ASSOCIATES ELECTED MARCH 10, 1916

*Alden, Carroll Russell, Instructor in Electrical Subjects, Detroit Technical Institute; res., 2400 Grand Blvd. W., Detroit, Mich.

Ammen, Walter, Chief Engineer, New York Office, Siemens-Schuckert and Siemens & Halske, 90 West St., New York, N. Y.

Armstrong, George E., Dept. of Generation, Southern California Edison Co., 320 San Fernando Bldg., Los Angeles, Cal.

Bills, Frank Berry, Engineer, Kinloch Telephone Co., Kinloch Building, 10th & Locust Sts., St. Louis, Mo.

Board, V. L., Rate Engineer, Henry L. Doherty & Co., 60 Wall St., New York, N. Y.

Bowen, Roy E., Operating Engineer, Elmira Water Light and Railroad Co.; res., 345 Irvine Place, Elmira, N. Y.

Boyd, Ezra Lee, Electrical Engineer, Installing Light and Power Plants, Mendon; res., Loraine, Ill.

Boyd, Richard Leroy, District Manager, Southern Bell Tel. & Tel. Co., Jacksonville, Fla.

*BROADBENT, WILLIAM WOLFE, Construction Engineer, Shore Line Electric Ry. Co., Norwich, Conn.

CLEGG, T. HERBERT, Engineering Assistant, Philadelphia Rapid Transit Co.; res., 1684 N. 54th St., Philadelphia, Pa.

CONNELL, HOWARD ROBLIN, Research Engineer, Allegheny Steel Co., Brackenridge, Pa.

*COOVER, MERVIN S., Operator, Montana Power Co., Three Forks, Mont.

CREAGER, F. L., Engineering Dept., Remy Electric Co.; res., 25 West Fifth St., Anderson, Ind.

CREESY, CLYDE KENNETH, Instructor in Mathematics, Bliss Electrical School, Takoma Park, D. C.

CROWLEY, JACK A., Engineering Dept., W. S. Barstow & Co., 50 Pine St., New York, N. Y.

DILLARD, EDWARD ALONZO, Assistant Engineer, Alabama Power Co.. 910 Brown Marx Bldg., Birmingham, Ala.

DITTMAR, RICHARD A., Jr., Assistant Superintendent of Power, Atlas Portland Cement Co., Hannibal, Mo.

DITTRICK, CLARE HOFFMAN, National Carbon Co., Cleveland; res., 1302 West Lake Ave., Lakewood Ohio.

FEIGE, CHARLES HENRY, Engineer, Tuinucú Sugar Co., Tuinucú, Cuba.

FITZGERALD, JAMES G., Meter Dept., Carolina Power and Light Co., Raleigh N. C.

*FOWLER, WALTER DOUGLAS, Senior Demonstrator, Electrical Dept., McGill University, Montreal; res., 388 Roslyn Ave., Westmount, P. Q., Canada.

FROST, HERBERT H., Buyer and Sales Engineer, Electrical Merchandise, Sears-Roebuck & Co., Chicago; res., 304 Forest Ave., Oak Park, Ill.

GOWEN, JOSEPH M., Plant Engineering Dept., New York Telephone Co., Long Island Div.; res., 1764 East 19th St., Brooklyn, N. Y.

GRANT, FRANK LINCOLN, JR.. Assistant Instructor, Third Avenue Railroad Co., res.. 678 St. Ann's Ave., New York N. Y.

*GREEN, SAMUEL GORDON, Professor of Electrical Engineering, Columbus Industrial School, Columbus, Ga.

*GROGINSKI, PHILIP S., Assistant, Dept. of Electrical Engineering, Agricultural and Mechanical College of Texas, College Station, Tex.

*GUIMARÃES, ANTONIO R., Electrical Engineer, Rio de Janeiro Tramway, Light & Power Co.; res., 39 Barão de Itamby, Rio de Janeiro, Brazil.

*HAMILTON, BAXTER PERRY, Engineering Dept., American Telephone & Telegraph Co., New York; res., 36 Park Ave., Jamaica, N. Y.

HARDY, GEORGE E. Instructor in Electrical Engineering, University of Vermont; res., 128 Colchester Ave., Burlington, Vt.

HARTLEY, RALPH VINTON LYON, Engineer, Research Branch, Western Electric Co., 463 West St., New York, N. Y.

HARTSHORNE, WILLIAM BIBB, Division Superintendent, Public Service Electric Co., 70 Gamewell St., Hackensack, N. J.

HAYASE, SHIMPEI, Electrical Engineer, Tabata Receiving Station, Inawashiro Hydro-Electric Power Co., Tabata, Tokyo, Japan.

HUTCHINSON, H. H., Superintendent, Vaudreuil Works, Canadian Explosives Limited, Vaudreuil Station, Quebec, Canada.

*JEFFERY, ROY CHRISTIAN, Construction Dept., General Electric Co., Schenectady, N. Y.; res., Guild, Tenn.

*JONES, LAURENCE DEAN, Consulting Engineering Dept., General Electric Co., Schenectady, N. Y.

KEENE, ALVIN DEWAYNE, Engineer, Industrial Control Dept., General Electric Co., Schenectady, N. Y.

KIRCHNER, HENRY P., Inspector, Canadian Niagara Power Co., Niagara Falls, Ont.; res., University Club, Niagara Falls, N. Y.

*KLAG, FREDERICK W., Instructor of Physics, Morrison Waite High School; res., 551 Palmwood Ave., Toledo, Ohio.

KORNER, ASEL JULIUS, Chief Engineer, Railway Dept., General Electric Co. of Sweden; res., Almelund 3, Westeras, Sweden.

LATZER, FREDERICK, Assistant Electrical Engineer, Lord Electric Co.; res., 423 E. 169th St., New York, N. Y.

LOVE, JOSEPH E., Chief Engineer, South Dakota Board of Railroad Commissioners, Pierre, S. D.

MAHER, JOHN F., Elevator Constructor, Municipal Building; res., 425 W. 44th St., New York, N. Y.

*MARKLE, E. W., Principal of High School, Hublersburg, Pa.

MATHEWS, EDWARD DANIEL KING, Asst to Chief Electrical Engineer, Electrical Standards Laboratory, Inland Revenue Dept., Ottawa, Canada.

MCALPINE, DOUGALD DUNCAN, Engineering Dept., Canadian General Electric Co., Ltd.; res., 387 Markham St., Toronto, Ontario.

MCCARTY, FRANCIS ALEXANDER, Consulting Electrical Engineer, 31 Queen St., Melbourne, Victoria, Australia.

MCCLELLAND, EDRIC RAYMOND, Foreman, Interior Construction (Eastern Div.), Public Service Co. of Northern Illinois, 10 Illinois St., Chicago Heights, Ill.

MCCULLOCH, GAVIN BUCHANAN, Resident Engineer, Electricity Works, Charters-Towers, Queensland, Australia.

*MIZUSHI, F. MASANAO, Westinghouse Electric & Mfg. Co., East Pittsburgh; res., Westinghouse Club, Wilkinsburg, Pa.

MORRISSEY, FRANK T., Superintendent, Municipal Light and Water Works, Winamac, Ind.

*NEWMAN, REA CAMBRIDGE, Engineering Dept., Pacific Tel. &Tel. Co.; res., 1207 Gough St., San Francisco, Cal.

PEATROSS, RICHARD WARNER, JR., Engineering Department, Texas Power & Light Co., Dallas, Texas.

*PETERSON, ALFRED J. A., Diagram Engineer, Westinghouse Electric & Mfg. Co.; res., 6338 Shakespeare St., Pittsburgh, Pa.

PIERCE, NIKOLA CARL, Superintendent, Kilbourn Plant, Southern Wisconsin, Power Co., Kilbourn, Wis.

POYNER, JAMES MARION, Salesman, General Electric Co., 1222 Munsey Building, Baltimore, Md.

PRYDE, D. S., Salesman, Westinghouse Electric & Mfg. Co., San Antonio, Texas.

*READY, WILLIAM ALOYSIUS, Electrical Engineer, Nipe Bay Co., Preston, Cuba.

REYNOLDS, RALPH WHITNEY, Chief Operator, Hydro-electric Dept., Cerro de Pasco Mining Co., Oroya, Peru, S. A.; res., 270 So. Harvard Blvd., Los Angeles, Cal.

SCHERIL, HENRY, Electrical Engineer, Testing Department, Crocker-Wheeler Co., Ampere, N. J.

SCHMIDT, JAY HANDLER, Chemical Engineer, National Carbon Co.; res., 11426 Clifton Road, Cleveland, Ohio.

SIMPSON, ERNEST DUNCAN, General Foreman of Electrical Work, Braden Copper Co., Rancagua, Chile, S. A.

STAUBITZ, LOUIS PIERCE, Electrical Operator, Commonwealth Edison Co.; res., 3210 Arthington St., Chicago, Ill.

STEINDORFF, KURT, Student Engineer, General Electric Co.; res., 702 Campbell Ave., Schenectady, N. Y.

STUART, LEMUEL MAHLON, Electrician, Tenafly Electrical Co., Tenafly, N. J.

SUNIER, WALTER HENRY, Material Engineer, General Electric Co.; res., 1211 Fairfield Ave., Fort Wayne, Ind.

TOY, JAMES IRVINE, Electrical Engineer, Wayne Knitting Mills, Fort Wayne, Ind.

*TSUCHIYA, SHUSEI, Student Engineer, General Electric Co.; res., 2 Harrison Ave., Schenectady, N. Y.

*WHEATLAKE, BURTON C. J., Transformer Commercial Engineer, General Electric Co.; res., 2357 Dahlia St., Denver, Colo.

*WITZEL, EARL RODEE, Storage Battery and Automobile Electric Starter Expert, Fred C. Bowles, Groton, So. Dakota.

WRAY, EDWARD, Business Manager, *Railway Electrical Engineer*, Woolworth Building, New York, N. Y.; res., Westfield, N. J.

Total 70.

*Former enrolled Students.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before April 30, 1916.

Argo, M. M., Acmar, Ala.
Ashton, J. O., Philadelphia, Pa.
Barclay, G. R., Schenectady, N. Y.
Baker, R. J., New York, N. Y.
Bayard, R. A. (Member), Chippawa, Ont.
Beardsley, H. (Fellow), Newark, N. J.
Benham, C. F., San Francisco, Cal.
Benton, J. R., Gainesville, Fla.
Bixby, W. P., Nashville, Tenn.
Breit, H. E., Palmerton, Pa.
Bulley, G. W. (Member), Chicago, Ill.
Bunch, C. H., Cleveland, O.
Busby, J. H., Detroit, Mich.
Callard, N. H., Salt Lake City, Utah
Clinton, W. B., Schenectady, N. Y.
Collins, W. F., Depew, N. Y.
Corcoran, J. H., Portland, Ore.
Davis, F. C., Charleston, S. C.
Decker, S. M. (Member), Fort Monroe, Va.
Edmunds, W. H., Denver, Colo.
Egbert, D. V., Chicago, Ill.
Fey, W. L., Balboa, C. Z.
Fischer, R. H., Pedro Miguel, C. Z.
Fisher, S. (Member), Bridgeport, Conn.
Flanders, H. W., Denver, Colo.
Fucik, R. A., Springfield, Ill.
Gilman, W. F., Beardstown, Ill.
Glaze, H. C., Denver, Colo.
Gordon, H. E., Rochester, N. Y.
Grimsley, A. H., Clifton Forge, Va.
Hamlen, H. H., New York, N. Y.
Harvey, J. L., Pittsburgh, Pa.
Hayner, D. E., Cambridge, Mass.
Hill, E. E., New York, N. Y.
Holcombe, W. E., Schenectady, N. Y.
James, G. C., Yonkers, N. Y.
Kardor, E., Hoboken, N. J.
Katsigris, T. C., New York, N. Y.
Kelly, J. A., Cleveland, O.
Kinkead, R. E., Cleveland, O.
Klumb, H. J., Rochester, N. Y.
Kommers, O. A., Corcoran, Cal.
Libbey, M. A., Washington, D. C.
Longenecker, W. B., Lancaster, Pa.
Lopez, E. F., Iquique, Chile, S. A.
Maloney, C. J., New York, N. Y.
Mangels, W. C., Newark, N. J.
Markley, G. E., Cleveland, O.
Maunder, H. N., Westport, N. Z.
Mauseau, C. M., Rio de Janeiro, Brazil
May, W. H., Cleveland, O.
McKelvey, C. F., Denver, Colo.
Mershon, A. V., Schenectady, N. Y.
Milner, G. S., Cleveland, O.
Morris, J. F., New York, N. Y.
Nelson, J. C., New York, N. Y.
Nelson, N. P., Lead, S. D.
Obermaier, J. A., Chicago, Ill.
Oliver, J. M., Birmingham, Ala.
Peridier, J., Paris, France
Proctor, E. B., Atlanta, Ga.
Quigley, L. L. (Member), Butte, Mont.
Riggs, A. F. (Member), Chicago, Ill.
Ruecke, C. H., Cleveland, O.
Saxton, C. W., Auckland, N. Z.
Schwartz, M., St. Paul, Minn.
Shaw, W., McKeesport, Pa.
Steward, W. M., Elmira, N. Y.
Stoddard, A. D., Kansas City, Mo.
Strickland, R. F., Cleveland, O.
Sully, S., New Haven, Conn.
Sultzer, P. O., Butte, Mont.
Summer, M. A. D., Buffalo, N. Y.
Taylor, V. E., Cos Cob, Conn.
Thirlwall, J. C., Schenectady, N. Y.
Walton, H. M., Atlanta, Ga.
Weightman, H. E., Chicago, Ill.
Westphal, H. C., Jersey Shore, Pa.
Wheat, G. J., Oakland, Cal.
Wheeler, H. E., Boston, Mass.
Woolfolk, W. G., Chicago, Ill.
Yang, S. Z., New York, N. Y.
Yoder, C. P., Erie, Pa.

Total 83.

STUDENTS ENROLLED MARCH 10, 1916

7935 Holt, E. Y., Ga. Sch. Tech.
7936 Colby, C. C., Jr., Univ. of Penna.
7937 Wood, W. C., Wentworth Inst.
7938 Dawes, D. F., Polytechnic Institute of Brooklyn.
7939 Bernhard, A. H., Polytechnic Institute of Brooklyn.
7940 Tree, E. W., Polytechnic Institute of Brooklyn.
7941 Goss, H. J., Polytechnic Institute of Brooklyn.
7942 Ledermann, F., Polytechnic Institute of Brooklyn.
7943 Snowden, J. W., Jr., Polytechnic Institute of Brooklyn.
7944 Young, A. W., Polytechnic Institute of Brooklyn.
7945 Seeley, W. J., Polytechnic Institute of Brooklyn.
7946 Fishel, J. E., Polytechnic Institute of Brooklyn.
7947 Wall, J. V. R., Polytechnic Institute of Brooklyn.
7948 Drake, W. V., Polytechnic Institute of Brooklyn.
7949 Andrae, G. H. J., Univ. of Wis.
7950 Butchinski, C., Bucknell Univ.
7951 Singletary, H. H., A. & M. College of Texas.
7952 Dickie, A., Jr., A. & M. College of Texas.
7953 Hatfield, A. W., Bucknell Univ.
7954 Sircar, B. B., Yale University.
7955 Aitchison, W. L., Wentworth Inst.
7956 Dwyer, W. R., Syracuse Univ.
7957 Gay, L. W., Syracuse University.
7958 Skagerberg, R., Univ. of Minn.
7959 Coker, M. B., Univ. of Arkansas.
7960 Wells, G. C., Univ. of Arkansas.
7961 Rice, P. X., Univ. of Arkansas.
7962 Poust, G. C., Bucknell Univ.
7963 Martin, C. A., Case School of Applied Science.
7964 Hall, H.W., Wentworth Institute.
7965 Smith, H. E., Bucknell Univ.
7966 Hopkins, A. E., Kans. St. Agri. College.
7967 Grone, H. S., Wentworth Institute
7968 Moore, J. P., Case School App. Science.
7969 Sechrist, G. H., Kans. State Agricultural College.
7970 Morrison, P. G., Mass. Inst. Tech.
7971 Gieseler, H. E., N. Y. Elec. Sch.
7972 O'Rourke, J. B., Iowa State Coll.
7973 Andrews, B. M., Kans. St. Agri. Coll.
7974 Oman, C., University of Kansas.
7975 Moore, J. W., Mich. Agri. Coll.
7976 Crimmin, E. V., Univ. of Maine.
7977 Gibson, A. B., Clarkson College of Technology.
7978 Rutter, A. R., Univ. of Pittsburgh.
7979 Lansche, O. A., Univ. of Ill.
7980 Brentlinger, C. M., Univ. of Ill.
7981 McNeil, K. H., Carnegie Inst. Tech.
7982 Dodge, H. F., Mass. Inst. Tech.
7983 Blume, W. T., Lewis Institute.
7984 Foster, D. S., Univ. of Missouri.
7985 Boll, L. P., Univ. of Missouri.
7986 McIntyre, C. T., Marquette Univ.
7987 Perris, N., Case Sch. App. Sci.
7988 Michel, C. A., Case Sch. App. Sci.
7989 Strnad, C., N. Y. Elec. School.
7990 Siddall, T. H., Jr., Clemson Coll.
7991 Simpson, J. W., Clemson College.
7992 Perry, D. J., Lafayette College.
7993 Simonds, H. F., Wentworth Inst.
7994 Graff, M. G., Mass. Inst. Tech.
7995 Samson, H. E., Univ. of Kansas.
7996 Ferrall, J. P., Jr., Catholic University of America.
7997 Ellefson, S., Univ. of Minn.
7998 Ellison, E. C., Univ. of Wis.
7999 Baker, S. F., Wentworth Inst.
8000 Stone, H. E., Univ. of Maine.
8001 Tatnall, A. R., Stanford Univ.
8002 Bird, F. S., Stanford Univ.
8003 Miller, H. P., Jr., Stanford Univ.
8004 Matson, J. J., Stanford Univ.
8005 Anderson, A. L., Stanford Univ.
8006 Lewis, H. W., Stanford Univ.
8007 Johnson, F. M., Armour Institute of Technology.
8008 Whitall, C.W., Mass. Inst. Tech.
8009 Cohen, S., Brooklyn Poly. Inst.
8010 Clark, H. W., Univ. of Utah.

Total 76.

EMPLOYMENT DEPARTMENT

NOTE: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-110. Draftsmen with experience on electrical apparatus, motors, generators, switchboards, transformers, controllers, etc. Address Chief Clerk, Engineering Department, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

V-112. Recent graduates in electrical engineering from schools of recognized standing are desired in testing work by large electric railway company. Those having some outside experience in maintenance and testing of electrical instruments will be given preference. State particulars of education, experience and salary desired.

V-115. Plant Manager, by a company manufacturing electric furnace products in Western New York. Must have good executive ability, manufacturing experience, and some knowledge of cost keeping. Must know how to cut down excessive costs. Experience with electric furnaces is desirable. Company employs a competent chemist. Applicant is asked to state experience, age, salary desired, and date upon which he would be available.

V-117. Electrical Engineering Instructor wanted for beginning of fall term in large engineering school in Atlanta, Ga. Must have some engineering degree. Some teaching experience desirable, but not absolutely necessary. Duties include teaching, laboratory instruction and research. Moderate salary to start but opportunities for advancement.

V-118. Experimental Engineering Instructor wanted for beginning of fall term in large engineering school in Atlanta, Ga. Must have some engineering degree. Some teaching experience desirable but not absolutely necessary. Duties include teaching, laboratory instruction and research. Moderate salary to start but opportunities for advancement.

V-119. Chemical Engineering Instructor wanted for beginning of fall term in large engineering school in Atlanta, Ga. Some teaching experience desirable, but not absolutely necessary. Must have some engineering degree. Duties include teaching, laboratory instruction and research. Moderate salary to start but opportunities for advancement.

V-120. Technical Graduate as instructor in physics for beginning of fall term in large engineering school in Atlanta, Ga. Must have some engineering degree. Some teaching experience desirable, but not absolutely necessary. Duties include teaching, laboratory instruction and research. Moderate salary to start but opportunities for advancement.

V-121. Technical Graduate as instructor in drafting for beginning of fall term in large engineering school in Atlanta, Ga. Must have some engineering degree. Some teaching experience desirable, but not absolutely necessary. Duties include teaching, drafting-room instruction and practical designing. Moderate salary to start but opportunities for advancement.

Applications will be received by the Municipal Civil Service Commission, Municipal Building, New York City, up to April 10, for the position of Deputy Chief, Bureau of Fire Prevention. Application blanks will be mailed upon request, provided postage is enclosed to cover mailing. Residence in New York State prior to this examination not necessary. Candidates must have had experience of an executive character tending to fit them for the responsibility of the work of a large number of employees. They must have had four years' experience as an engineer, inspector or investigator in work relating to fire hazards and appliances, or in such capacity as to direct, supervise or regulate building construction or occupancy, or similar experience. Two years' experience will be allowed to holders of appropriate degrees or to those submitting evidence of having pursued for a sufficient length

of time courses leading to such degrees as would fit them for work of this character.

Salary $3,000 per annum at present. The Bureau of Standards has recommended to the Board of Estimate that the salary range for this position should be $3,600 to $4,200.

A U. S. Civil Service Examination for Laboratorian will be held on May 3, 1916, at numerous places in the U. S., to fill a vacancy at $3.60 per diem in the Machinery Division of the Navy Yard, Mare Island, Cal., and similar vacancies as they may occur.

Applicants must have received (or show that they will receive not later than June 30) a bachelor of science degree; or have had at least two years' practical experience in electrical engineering.

Persons who desire this examination should at once apply for the circular announcing this examination (Form 451, issued March 24) and Form 1312, stating the title of the examination for which the form is desired, to the United States Civil Service Commission, Washington, D. C., or if time is limited it is suggested that inquiry be made at the nearest post office or custom house.

MEN AVAILABLE

445. Mechanical-Electrical Engineer. Chief Electrician, Master Mechanic. Age 35; practical, technical, executive, organizer. Fifteen years with telephone, railroad, smelter and mining companies. Absolutely clear record; desires position of responsibility and trust with going industrial, railroad, mining or smelting corporation. Present salary, $2,400.

446. Electrical Engineer, technical graduate, Westinghouse apprentice, ten years' experience, construction and operation of hydroelectric power plants, substations, transmission lines and mining equipment, wishes to take up design or construction work with an engineer, contractor or large operating company. Available April 1.

447. Superintendent-Manager. Sixteen years in present position with large power company on Pacific coast in charge of operation, maintenance and distribution of hydroelectric plant. Large experience with electric power as applied to mining. Reason for change, present field too small. Available April 1st.

448. Electrical Engineer, technical and university graduate, good correspondent, ten years' experience, mostly selling, with electric manufacturers; desires position with manufacturing or public utility company.

449. Electrical Engineer, technical graduate: age 32; married. Nine years' experience in the supervision, design, construction, operation and maintenance of hydroelectric stations, pumping plants, substations, transmission lines and distributing systems. Also surveying, drafting, inventories, appraisals, costs, etc. Open for engagement May 1, or upon reasonable notice.

450. Mechanical and Electrical Engineer, Cornell graduate, with extensive experience designing, constructing, maintaining, operating, managing and office engineering, desires position where such experience would be required. Now chief mechanical and electrical engineer designing, constructing, maintaining and operating explosive plants. Duties relative to operation of minor importance, reason for change.

451. Graduate Electrical-Mechanical Engineer, 27 years of age, having had six years' practical experience, desires a position as assistant superintendent or superintendent of a manufacturing concern. Experienced in the detail work of a superintendent, following up labor, material and operations, development of new products, and technical details.

452. Electrical and Civil Engineer, experienced in design, construction and operation of steam and hydroelectric plants and in modern business methods, desires position of responsibility, such as manager of small company or chief engineer of large plant. Minimum salary $3,000.

453. Electrical Engineer, technical graduate, fourteen years' experience in the operation, construction and design of power plants and substations on low- and high-tension systems. Age 33. Would take position as electrical engineer, superintendent of construction or superintendent of moderate-size system.

454. Experienced Executive wishes to make permanent connection with manufacturer of electrical machinery. Practical experience of sixteen years includes drafting, testing, designing and manufacturing, also sales and general management. Have had responsible charge of entire business for considerable time. Would take charge of branch office, but preference given to factory position.

455. Electrical Engineer, with a private 150,000-volt laboratory near Philadelphia, available for high-voltage and

ionization problems. Thirteen years' experience.

456. Graduate Electrical Engineer, desires spare time employment; available six hours during day. Desires drafting work, checking computations, detail or other technical work. Has practical and theoretical experience in telephone, street lighting and steam plant work. Has been doing drafting work in spare time for last three years.

457. Electrical Tester, educated, seven years' experience. At present employed by a large water power company in testing laboratory. Desires to change, but only to a city; will not consider traveling. Married; age 28; moderate salary.

458. Electrical Engineer, twelve years' experience, three in Europe and nine years for American firm, desires to be representative for Italy for American electrical concern. English, French, German, Italian and Spanish languages well known.

459. Electrician, having twelve years' practical experience in power station construction, operation large lighting installations, motor installations, construction and maintenance industrial plants. Good executive ability; evening school student electrical engineering. Married; age 28. New York or vicinity. At present employed.

460. Graduate Engineer, with three years' experience teaching electrical engineering and four years' experience in commercial electrical design, is open for engagement as teacher of electrical engineering theory and design for next fall. Twenty-nine years old; married. Further information given and interview arranged in correspondence.

461. Electrical Engineer, age 30; unmarried. Eight years' experience with operating company in Western Canada; desires position as assistant engineer or superintendent with power company. (Western States preferred.) Four years' college course with diploma, and shop experience.

462. If you need new blood in your company that will eliminate your avoidable accidents and delays, write for my past history and reasons why I feel confident I can guarantee to accomplish the above result. Will accept $150 per month for immediate employment.

463. Electrical Engineer, desires position as sales engineer or factory executive. Six years' factory and designing work and two years' experience on sales. An expert on d-c. motors and generators and a good general knowledge of other apparatus. Age 27; unmarried. At present employed.

464. Instructor in Electrical Engineering with ability to teach classes in both theoretical and laboratory work. Familiar also with practise in one of the largest electrical manufacturing companies. A good executive. Not afraid to work.

465. Competent Electrician, experienced in power plant, pole line, storage battery and substation construction and operation. Eighteen years' experience, ten in western mining camps. High- or low-tension apparatus, shaft or surface work. Good workman; can handle men. Married; sober; tools. Will go anywhere.

466. Construction Electrician, fifteen years' experience on a-c. and d-c. apparatus, isolated plant, conduit and line construction, Can plan and lay out installations. At present employed with large concern in charge of electrical construction. Desires larger field and permanent location. •

467. Electrical Engineer, experienced in electrical and mechanical design of d-c. turbo-generators and d-c. motors, would like position with reputable concern. Technical graduate; twelve years engineering practise. At present holding leading position with well-known firm.

468. Sales Engineer, American, 25, graduate leading Eastern technical school, at present engaged in engineering work in South America, wishes to enter into negotiations with company manufacturing engineering specialties, with idea of future representation in South America. Excellent sales and works records; knowledge of business conditions; fluent Spanish.

469. Technical graduate, age 31, ten years' practical experience in engineering design and construction with large public utility companies. Familiar with power plant and substation layouts, specifications, reports, estimating and cost analysis. Can supervise drafting and construction work. At present employed but desires to locate with company offering greater opportunity for advancement.

ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Data On Municipal Plant Operation in Oklahoma. By H. B. Bozell. Norman, Okla., 1916. (Gift of author.)

Linear Hot Wire Anemometer and its applications in technical physics. By L. V. King. (Reprinted from Journal of the Franklin Institute, Jan. 1916) Philadelphia, 1916. (Gift of author.)

Los Angeles. Board of Public Utilities. Annual Report 6th, 1914-15. (Gift of Los Angeles Board of Public Utilities.)

UNITED ENGINEERING SOCIETY

Erläuterungen zu den Normalien für isolierte Leitungen in Starkstromanlagen, den Normalien für isolierte Leitungen in Fernmeldeanlagen sowie den Kupfernormalien. By Richard Apt. Berlin, 1915. (Purchase.)

Institute of Radio Engineers. Year Book, 1916. New York, 1916. (Purchase.)

Lehrbuch der Elektrochemie von Svante Arrhenius. Leipzig, 1915. (Purchase.)

Leitfaden der drahtlosen Telegraphie fur die Luftfahrt. By Max Dieckmann. München, 1913. (Purchase.)

McGraw Electrical Directory. Railway Edition, February 1916. New York, 1916. (Purchase.)

Power for Profit. By R. P. Bolton. New York, 1915. (Purchase.)

GIFT OF CARL HERING

American Institute of Electrical Engineers. Report of the Standard Wiring Table Committee. Matthiessen's Standard of Resistance of Copper.

Ayrton, W. E. & Cooper, W. R. Variations in the Electromotive force of Clark Cells with temperature. (From Royal Society Proceedings, vol. 59.)

Ayrton, W.E. & Haycraft, H.C. Students' Simple Apparatus for Determining the Mechanical Equivalent of Heat. (From Philosophical Magazine, Feb. 1895.)

Ayrton, W.E. & Mather, T. The Construction of Non-Inductive Resistances. (From Philosophical Magazine, Feb. 1892.)

——Galvanometers. Philosophical Magazine Nov. 1896.)

——Electrostatic Reflecting Voltmeter. (Trade catalogue.)

Ayrton, W. E. & Sumpner, W. E. Galvanometers (From Philosophical Magazine, July 1890.)

——Alternate Current and Potential Difference Analogies in the methods of measuring power. (From Philosophical Magazine, Aug. 1891.)

——Measurement of the Power given by any electric current to any circuit. (From Proceedings of the Royal Society, vol. 49.)

Ayrton, W. E., J. Perry & W. E. Sumpner. Quadrant Electrometers. (From Proceedings of the Royal Society, vol. 50.)

Ayrton, W. E. & Perry, John. Laboratory Notes on Alternate Current Circuits. (From Proceedings, Institution of Electrical Engineers, vol. xviii.)

Ayrton W. E., & Taylor, J. F. Proof of the generality of certain formulae published for a Special Case by Mr. Blakesley. (From Philosophical Magazine, Apr. 1891.)

Blondel, A. L'hystérésimètre Blondel-Carpentier et son application a la mesure statique de l'hysteresis.

——L'Eclairage Public par les Lampes a arc. Paris 1895.

——Photometric magnitudes and units. London, n.d.

——Théorie des Projecteurs Electriques. Paris, 1894.

Competition for the Construction of Meters of Electrical Energy, 1889. Programme.

Dolivo-Dobrowolsky, M. v. Der Drehstrom und seine entwicklung.

——Kraftübertragung mettels Wechselströmen von verschiedener Phase (Drehstrom). From Electrotechniker, 1891.)

Forbes, Geo. On the relation which ought to subsist between the strength of an electric current and the diameter of conductors, to prevent overheating. 1881.

Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts. Report of a special committee to determine the efficiency and duration of incandescent electric lamps. Philadelphia, 1885.

Hopkinson, J. & Wilson, E. Propagation of magnetization of iron as affected by the electric currents in the iron. London, 1895.

Kallir, Ludwig. Ueber das Verhalten des Wehnelt'schen Unterbrechers im Wechselstromkreise. (From Zeitschrift fur Elektrotechnik, 1899.)

Kunstliches Oberlicht. 1891. (From Schillings Journal fur Gasbeleuchtung und Wasserversorgung, 1891.)

Lord Kelvin's Standard Electric Instruments. Ed. 10, 1893.

Nerz, F. Scheinwefer und deren Verwendung. (From Zeitschrift des Vereines deutscher Ingenieure, vol xxxvi, 1892.)

Notice sur l'inductomètre Miot.

Perry, J. & Sumpner, W. E. Quadrant electrometers. (From Philosophical Transactions, of Royal Society of London, vol. 182, A.)

Puluj, J. Strahlende elektroden materie und der sogenannte vierte Aggregatzustand. Wien, 1883.

Reeves, J. H. Addition to the Wheatstone Bridge for the determination of low resistances. (From Philosophical Magazine, May, 1896.)

Report on Power Transmission Tests—Lauffener works, Frankfort, 1891.)

Roessler, G. Die graphische darstellung der Vorgänge in Wechselstromkreisen bei beliebigen Spannungskurven. (From Elektrotechnischen Zeit. 1895.)

Squier, Geo. O. Electrochemical effects due to Magnetization. (Reprint from American Journal of Science, 1893.)

GIFT OF CARY T. HUTCHINSON

Science Abstracts. vols. 1-10 (Sect. A-B): vols. 11-13, (Sect. B); vols. 14-18, (Sect. A-B). London, 1898-1915.

United States Geological Survey. Water Supply Papers. Nos. 1-288. Washington, 1896-1912.

GIFT OF NATIONAL BOARD OF FIRE UNDERWRITERS

List of Electrical Fittings. October. 1915.

Regulations for Electric Wiring and Apparatus. 1915.

Regulations for the installation of Rotary and Centrifugal Fire Pumps and for the Electrical Driving of Fire Pumps, 1913.

Rules and Requirements for the construction and installation of Signaling Systems used for the transmission of signals affecting the fire hazard, 1913.

GIFT OF WESTINGHOUSE, CHURCH, KERR & COMPANY

A good collection of text books of which the following books on electrical subjects were added to the Library:

Atwood, L. C. Practical Dynamo Building. 1893.

Badt, F B. Dynamo tender's handbook. Ed. 4. 1891.

Bottone, S. R. Electro motors. 1891.

Boult, W. S. Comprehensive international wire table. 1890.

Day, R. E. Exercises in electrical and magnetic measurement Ed 7. 1896.

Desmond, Charles. Electricity for engineers. 1891.

Fitz-Gerald, D. G. Lead storage battery. n.d.

Fleming, J. A. Short lectures to electrical artisans. 1890.

Guy, A. F. Electric light and power. 1894.

Hering, Carl. Principles of dynamo-electric machines. 1889.

Inspector and the trouble man. 1900.

Jackson, D. C. Text book on electro-magnetism. vol. I. 1893.

Joyce, Samuel. Examples in electrical engineering. 1896.

Karapetoff, V. Electrical engineering laboratory notes for seniors. 1905-06.

Lockwood, T. D. Electricity, magnetism, and electric telegraphy. Ed. 3, 1890.

May's Table for electrical conductors. n.d.

Niblett, J. T. Secondary batteries.

Salomons, David. Electric light installations. vol. II, III. Ed. 7.

Snell, A. T. Electric motive power. 1894.

Trevert, Edw. Practical directions for armature and field magnet winding. 1901.

Urquhart, J. W. Electric Light. Ed. 4, 1891.
——Electric light fitting. 1890.

Webber, W. H. V. Science and practice of lighting. 1892.

OFFICERS AND BOARD OF DIRECTORS, 1915-1916.

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*Deceased.

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Revised to April 1, 1916

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H. L. Blackwell, M. I. Pupin,
L. W. Chubb, E. B. Rosa,
W. S. Franklin, H. J. Ryan,
H. Clyde Snook.

INDUSTRIAL POWER COMMITTEE.

David B. Rushmore, Chairman,
General Electric Company, Schenectady, N.Y.
E. A. Lof, Secretary, 214 Glenwood Boulevard,
Schenectady, N. Y.

W. W. Briggs, C. D. Knight,
A. C. Eastwood, J. P. Mallett,
J. E. Fries, E. H. Martindale,
J. M. Hipple, A. G. Pierce,
H. D. James, W. H. Powell.

COMMITTEE ON RECORDS AND APPRAISALS OF PROPERTIES.

Philander Betts, Chairman,
790 Broad Street, Newark, N. J.

W. H. Blood, Jr., William McClellan,
Fred A. Bryan, W. J. Norton,
C. L. Cory, C. L. Pillsbury,
Henry Floy, H. Spoehrer,
W. B. Jackson, W. G. Vincent,
C. W. Wilder.

EDUCATIONAL COMMITTEE.

V. Karapetoff, Chairman,
Cornell University, Ithaca, N. Y.

E. J. Berg, G. A. Hoadley,
F. L. Bishop, A. S. Langsdorf,
Morgan Brooks, C. E. Magnusson,
C. R. Dooley, Charles F. Scott,
P. B. Woodworth.

IRON AND STEEL INDUSTRY COMMITTEE.

T. E. Tynes, Chairman,
Lackawanna Steel Co., Buffalo, N. Y.

A. C. Dinkey, W. O. Oschmann,
Gano Dunn, K. A. Pauly,
C. T. Henderson, J. C. Reed,
Wilfred Sykes.

SPECIAL COMMITTEES

Revised to April 1, 1916

PUBLIC POLICY COMMITTEE.

Calvert Townley, Chairman,
165 Broadway, New York.
William McClellan, Vice-Chairman,
141 Broadway, New York.

John A. Britton, John H. Finney,
H. W. Buck, H. A. Lardner,
Frederick Darlington, E. W. Rice, Jr.,
Gano Dunn, L. B. Stillwell,
H. G. Stott.

COMMITTEE ON DEVELOPMENT OF WATER POWER.

Calvert Townley, Chairman,
165 Broadway, New York.

H. W. Buck, H. A. Lardner,
Gano Dunn, L. B. Stillwell,
John H. Finney, H. G. Stott.

U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION.

C. O. Mailloux, President,
20 Nassau Street, New York.
F. B. Crocker, Vice-President,
A. E. Kennelly, Secretary,
Harvard University, Cambridge, Mass.

C. A. Adams, E. B. Rosa,
B. A. Behrend, Charles F. Scott,
Louis Bell, Clayton H. Sharp,
James Burke, Samuel Sheldon,
Gano Dunn, C. E. Skinner,
H. M. Hobart, Charles P. Steinmetz,
John W. Lieb, H. G. Stott,
R. B. Owens, Elihu Thomson,
M. I. Pupin, Philip Torchio.

HISTORICAL MUSEUM COMMITTEE.

T. C. Martin, Chairman,
29 West 39th Street, New York.

Charles L. Clarke, E. W. Rice, Jr.,
Louis Duncan, Charles F. Scott,
Frank J. Sprague.

CONSTITUTIONAL REVISION COMMITTEE.

Bancroft Gherardi, Chairman,
A. T. and T. Company, 15 Dey Street,
New York.

F. L. Hutchinson, W. S. Rugg,
Dugald C. Jackson, S. D. Sprong,
P. M. Lincoln, Charles W. Stone,
A. S. McAllister, H. G. Stott,
William McClellan, P. H. Thomas,
W. S. Murray, Calvert Townley,
W. D. Weaver.

PATENT COMMITTEE.

Ralph D. Mershon, Chairman,
80 Maiden Lane, New York.

Bion J. Arnold, M. I. Pupin,
C. S. Bradley, E. F. Northrup,
Val. A. Fynn, O. S. Schairer,
L. A. Hawkins, C. E. Scribner,
John F. Kelly, Frank J. Sprague,
Charles A. Terry.

COMMITTEE ON CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT.

George F. Sever, Chairman,
13 Park Row, New York.

A. H. Babcock, Gano Dunn,
H. W. Buck, John F. Kelly,
Schuyler Skaats Wheeler.

COMMITTEE ON RELATIONS OF CONSULTING ENGINEERS.

L. B. Stillwell, Chairman,
100 Broadway, New York.
H. W. Buck, F. R. Ford,
Gano Dunn, A. M. Hunt,
F. N. Waterman.

MEMBERSHIP COMMITTEE.

W. A. Hall, Chairman,
General Electric Company, West Lynn, Mass.
H. W. Blake, M. G. Lloyd,
S. H. Blake, E. H. Martindale,
H. E. Bussey, O. T. Smith,
L. L. Edgar, E. A. Wagner,
H. A. Hornor, John B. Whitehead,
A. G. Jones, F. E. Wynne.

PROPOSED RESERVE CORPS OF ENGINEERS.

Bion J. Arnold, Chairman,
105 South La Salle Street, Chicago, Ill.
John Harisberger, A. M. Schoen,
Ralph D. Mershon, Charles W. Stone.

EDISON MEDAL COMMITTEE.

Appointed by the President for terms of five years.
Term expires July 31, 1916.
Schuyler Skaats Wheeler, Chairman,
Ampere, N. J.
Ralph D. Mershon, Frank J. Sprague.

Term expires July 31, 1917.
A. E. Kennelly, Robert T. Lozier.
S. G. McMeen.

Term expires July 31, 1918.
H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.
Charles F. Brush, William Stanley.
N. W. Storer.

Term expires July 31, 1920.
Carl Hering, Harris J. Ryan,
H. G Stott.

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1916.
C. O. Mailloux, L. T. Robinson,
Farley Osgood.

Term expires July 31, 1917.
B. A. Behrend, Paul M. Lincoln,
William McClellan.

Ex-Officio.

John J. Carty, President,
George A. Hamilton, Treasurer.
F. L. Hutchinson, Secretary.

INSTITUTE REPRESENTATIVES

ON BOARD OF AWARD, JOHN FRITZ MEDAL.
Ralph D. Mershon, Paul M. Lincoln.
C. O. Mailloux, John J. Carty,

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.
H. H. Barnes, Jr., Gano Dunn,
Samuel Sheldon.

ON LIBRARY BOARD OF UNITED ENGINEERING SOCIETY.
Samuel Sheldon, Harold Pender,
Edward D. Adams, W. I. Slichter,
F. L. Hutchinson.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.
The chairman of the Institute's Code Committee.

ON ADVISORY BOARD OF AMERICAN YEAR-BOOK.
Edward Caldwell.

ON ADVISORY BOARD, NATIONAL CONSERVATION CONGRESS.
Calvert Townley.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.
W. S. Franklin, G. W. Pierce.

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.
Calvert Townley, William McClellan.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.
Charles F. Scott, Samuel Sheldon.

ON AMERICAN ELECTRIC RAILWAY ASSOCIATION COMMITTEE ON JOINT USE OF POLES.
Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON NATIONAL JOINT COMMITTEE ON OVERHEAD AND UNDERGROUND LINE CONSTRUCTION.
Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON JOINT NATIONAL COMMITTEE ON ELECTROLYSIS.
Bion J. Arnold, F. N. Waterman,
Paul Winsor.

ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION.
A. E. Kennelly, C. O. Mailloux,
Clayton H. Sharp.

ON JOINT COMMITTEE ON CLASSIFICATION OF TECHNICAL LITERATURE.
F. B. Jewett.

ON ENGINEERING FOUNDATION BOARD.
Michael I. Pupin.

ON NAVAL CONSULTING BOARD.
Benjamin G. Lamme, Frank J. Sprague.

ON PAN-AMERICAN ENGINEERING COMMITTEE.
Gano Dunn, William McClellan,
John H. Finney, Charles W. Stone,
Calvert Townley.

LOCAL HONORARY SECRETARIES.
Guido Semenza, N. 10 Via S. Radegonda, Milan, Italy.
Robert Julian Scott, Christchurch, New Zealand.
T. P. Strickland, N. S. W. Government Railways, Sydney, N. S. W.
L. A. Herdt, McGill Univ., Montreal, Que.
Henry Graftio, Petrograd, Russia.
Richard O. Heinrich, Genest-str. 5, Schoeneberg, Berlin, Germany.
A. S. Garfield, 67 Avenue de Malakoff Paris, France.
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.
John W. Kirkland, Johannesburg, South Africa.

LIST OF SECTIONS

Revised to April 1, 1916.

Name and when Organie d		Chairman	Secretary
Atlanta	Jan. 19, '04	A. M. Schoen	H.E. Bussey, Third Nat. Bk. Bldg. Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead	L. M. Potts, Industrial Building, Baltimore, Md.
Boston	Feb. 13, '03	L. L. Elden	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago	1893	W. J. Norton	Taliaferro Milton, 613 Marquette Building, Chicago, Ill.
Cleveland	Sept. 27, '07	E. H. Martindale	Irving H. Van Horn, National Lamp Works, Nela Park, Cleveland, Ohio.
Denver	May 18, '15	W. A. Carter	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor	Jan. 13, '11	Ralph Collamore	C. E. Wise, 427 Ford Bldg., Detroit, Mich.
Fort Wayne	Aug. 14, '08	J. J. Kline	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Ind.
Indianapolis-Lafayette	Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Los Angeles	May 19, '08	E. Woodbury	R. H. Manahan, 32 City Hall, Los Angeles, Cal.
Lynn	Aug. 22, '11	G. N. Chamberlin	F. S. Hall, Gen.Elec.Co., West Lynn, Mass.
Madison	Jan. 8, '09	M. C. Beebe	F. A. Kartak, Univ. of Wis., Madison, Wis.
Mexico	Dec. 13, '07		
Milwaukee	Feb. 11, '10	R. B. Williamson	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota	Apr. 7, '02	E. T. Street	Walter C. Beckjord, St. Paul Gas Light Co., St. Paul, Minn.
Panama	Oct. 10, '13	William H. Rose	C. W. Markham, Balboa Heights, C. Z.
Philadelphia	Feb. 18, '03	J. H. Tracy	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh	Oct. 13, '02	T. H. Schoepf	G. C. Hecker, 436 Sixth Avenue, Pittsburgh, Pa.
Pittsfield	Mar. 25, '04	M. O. Troy	F. R. Finch, General Electric Company, Pittsfield, Mass.
Portland, Ore.	May 18, '09	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Rochester	Oct. 9, '14	E. L. Wilder	F. E. Haskell, 93 Monica Street Rochester New York.
St. Louis	Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco	Dec. 23, '04	A. H. Babcock	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady	Jan. 26, '03	L. T. Robinson	F. W. Peek, Jr., Gen. Elec. Co., Schenectady, N. Y.
Seattle	Jan. 19, '04	C. E. Magnusson	C. F. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Spokane	Feb. 14, '13	Victor H. Greisser	C. A. Lund, Washington Water Power Co., Spokane, Washington.
Toledo	June 3, '07	W. E. Richards	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto	Sept. 30, '03	D. H. McDougall	
Urbana	Nov. 25, '02	P. S. Biegler	T. D. Yensen, Univ. of Illinois, Urbana, Ill.
Vancouver	Aug. 22, '11	R. F. Hayward	H. N. Keifer, Northern Electric Company, Ltd., Vancouver, B. C.
Washington, D. C.	Apr. 9, '03	R. H. Dalgleish	Arthur Dunlop, National Electric Supply Company, Washington, D. C.

Total 32

LIST OF BRANCHES

Name and when Organized		Chairman	Secretary
Agricultural and Mech. College of Texas	Nov. 12, '09	A. Dickie	G. B. Hanson.
Alabama, Univ. of	Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of	Mar. 25, '04	P. X. Rice	F. M. Ellington, University of Arkansas, Fayetteville, Ark.
Armour Institute	Feb. 26, '04	A. A. Oswald	J. F. Hillock, Armour Institute of Technology, Chicago, Ill.
Brooklyn Poly. Inst.,	Jan. 14, '16	Albert H. Bernhard	Walter J. Seeley, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University	May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of	Feb. 9, '12	J. V. Kimber	H. A. Mulvaney, 1521 Hopkins Street, Berkeley, Cal.
Carnegie Inst. of Tech.	May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of	Apr. 10, '08	W. A. Steward	R. H. Kruse, 75th and Main Streets, Cincinnati, Ohio.
Clarkson Col. of Tech.	Dec. 10, '15	W. A. Dart	C. J. Dresser, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col.	Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College	Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of......Dec. 16, '04	E. F. Peterson	Samuel J. Blythe, University of Colorado, Boulder, Colo.
Georgia School of Technology..............June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College..Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.........June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College.....Apr. 15, '03	F. H. Hollister	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.........May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agric. Col., Manhattan, Kansas.
Kansas, Univ. of.......Mar. 18, '08	E. C. Arnold	E. C. Burke, 1214 Kentucky Street, Lawrence, Kansas.
Kentucky, State Univ. of Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College......Apr. 5, '12	Rodman Fox	Frank H. Schlough, Lafayette College, Easton, Pa.
Lehigh University......Oct. 15, '02	A. F. Hess	R. W. Wiseman, Lehigh University, South Bethlehem, Pa.
Lewis Institute.........Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of........Dec. 26, '06	A. A. Packard	E. V. Crimmin, Univ. of Maine, Orono, Me.
Michigan, Univ. of.....Mar. 25, '04	U. M. Smith	N. F. Brown, University, of Michigan, Ann Arbor, Mich.
Missouri, Univ. of......Jan. 10, '03	K. Atkinson	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col......May 21, '07	Taylor Lescher	J. A. Thaler Montana State College, Bozeman, Mont.
Nebraska, Univ. of......Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts......Feb. 11, '10	R. V. Davis	R. L. Kelly, West Raleigh, N. C.
North Carolina, Univ. of. Oct 9 '14	P. H. Daggett	
Ohio Northern Univ.....Feb. 9, '12	H. H. Robinson	F. W. Evans, 302 E. Lincoln Avenue, Ada, Ohio.
Ohio State Univ........Dec. 20, '02	R. G. Locket	D. A. Dickey, Ohio State University, Columbus, Ohio.
Oklahoma, Agricultural and Mech. Col...........Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	Clifford O. Oster	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon Agr. Col........Mar. 24, '08	Winfield Eckley	J. A. Hooper, Oregon Agric. College, Corvallis, Ore.
Penn. State College.....Dec. 20, '02	C. L. Knotts	William W. Herold, Jr., State College, Pa.
Pittsburgh, Univ. of....Feb. 26, '14	G. R. Patterson	W. K. Benz, University of Pittsburgh, Pittsburgh, Pa.
Purdue University......Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Rensselaer Poly. Inst....Nov. 12, '09	W. J. Williams	S. N. Galvin, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst...Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col. Mar. 14, '13	C. E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ..........Dec. 13, '07	A. B. Stuart	H. J. Rathbun, Stanford University, Cal.
Syracuse Univ..........Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of........Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin, Tex.
Throop College of Technology..............Oct. 14, '10	J. W. DuMond	K.W. Rich, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute................Jan. 8, '15	V. Dixon	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of........Feb. 9, '12	W. S. Rodman	J.H. Moore, Dawsons Row, University, Va.
Wash. State Col. of.....Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Coll. of Wash. Pullman, Wash.
Washington Univ.......Feb. 6, '04	P. C. Roberts	Charles A. Lieber, Washington University, St. Louis, Mo.
Washington Univ. of....Dec. 13, '12	E. C. Miller	Geo. S. Smith, Univ. of Washington, Seattle, Wash.
West Virginia Univ......Nov. 13, '14	H. C. Schramm	C. L. Walker, West Virginia Univ., Morgantown, W. Va.
Worcester Poly, Inst.....Mar. 25, '04	R. M. Thackeray	C. C. Whipple, Worcester Polytechnic Institute, Worcester, Mass.
Yale University. ......Oct. 13, '11	P.G. von der Smith	S. R. Large, 343 Elm Street, New Haven, Conn.

Total 54.

American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXV | MAY, 1916 | Number 5

A. I. E. E. ANNUAL MEETING, NEW YORK, MAY 16, 1916

The annual business meeting of the American Institute of Electrical Engineers will be held at the headquarters of the Institute, Tuesday, May 16, at 4:30 p.m. The Board of Directors will present its report for the fiscal year ending April 30, 1916, which will include a detailed statement of the financial status of the Institute and a summary of the work accomplished by the standing and special committees during the year. The Committee of Tellers will present its report on the result of the election of officers for the coming administrative year.

NATIONAL MEETING, MAY 16, 1916

To Be Held Simultaneously by Means of Long-Distance Telephone Service, in San Francisco, Chicago, Atlanta, Philadelphia, New York and Boston.

A national meeting of the American Institute of Electrical Engineers, to commemorate the achievements of its members in the fields of communication, transportation, lighting and power, will be held jointly in the above-mentioned cities by long-distance telephone service. All of the auditoriums in which the meetings are held will be connected by telephone circuits, and every seat in each hall will be provided with a telephone receiver so that everyone in attendance will be able to hear the proceedings in each of the participating gatherings in other cities in turn.

Speakers

The President of the A. I. E. E. will preside at New York and there will be a local presiding officer and principal speaker at each of the other cities. The place and time of meetings, and the principal speaker in each city, are given in the schedule herewith.

Opening Ceremonies

The meeting will be opened by President Carty, who will address allthe above cities simultaneously by telephone, following which will be greetings by prominent members of the Institute in different parts of the country, and other proceedings of interest conducted by telephone.

Local Addresses

The second part of the program will consist of an address by the principal speaker in each city to the local audience only, and will occupy about 30 minutes. The name of the speaker in each city is given in the accompanying schedule.

Closing Ceremonies

At the close of the simultaneous addresses, telephone greetings will be transmitted from each city to all of the other gatherings, and musical selections will be rendered by telephone between the different cities. Local orchestras will provide music at the various meet-

ings which will not be transmitted by telephone.

Tickets of Admission

Owing to the limited capacity of the halls in which the meetings are to be held, admission will be by ticket. Invited guests of the Institute will upon receipt of acceptance be furnished with tickets for reserved seats.

Application for Tickets

Applications for tickets should be made promptly to the person designated in the accompanying schedule at the city in which it is desired to attend the meeting. Tickets for the meeting in any city can be furnished only by the person designated for that city. Ticket holders should be in their seats at least **ten minutes before the opening of the meeting,** at which time the doors will be thrown open to all members, with or without tickets.

F. L. HUTCHINSON,
Secretary.

May 1, 1916.

SCHEDULE OF NATIONAL A. I. E. E. MEETING

City and time	Meeting place	Principal speaker	Apply for admission tickets to
BOSTON 8:30 p.m.	Franklin Union, Berkeley and Appleton Sts.	Dr. A. Lawrence Lowell President of Harvard University	Ira M. Cushing Room 820 84 State Street.
NEW YORK 8:30 p.m.	Engineering Societies Building, 33 W. 39th St.	Dr. H. S. Pritchett President Carnegie Foundation	F. L. Hutchinson, Sec. A. I. E. E. 33 W. 39th St.
PHILADELPHIA 8:30 p.m.	Witherspoon Hall Walnut & Juniper Streets	Dr. Edgar F. Smith Provost of University of Pa.	Wm. F. James 1442 Widener Bldg.
ATLANTA 7:30 p.m.	Taft Hall	Dean C. E. Ferris Engineering Faculty University of Tenn.	A. M. Schoen Trust Company of Georgia Bldg.
CHICAGO 7:30 p.m.	Congress Hotel Michigan Boulevard	Dr. Harry Pratt Judson President of University of Chicago	T. Milton 140 South Dearborn St.
SAN FRANCISCO 5:30 p.m.	Native Sons Hall 430 Mason St.	Dr. Ray C. Wilbur, Pres. Leland Stanford Jr. University	A. H. Babcock 1044 Flood Building.

NOTE: Owing to the limited number of seats available, members attending the New York and Philadelphia meetings can be furnished with only one admission ticket, and ladies will not be invited.

For the Boston, Chicago and Atlanta meetings two tickets per member are available, and ladies may be invited.

For the San Francisco meeting three tickets per member are available, and ladies may be invited.

A. I. E. E. ANNUAL CONVENTION, JUNE 27-30, 1916

The plans of the Convention Committee in preparation for the Annual Convention of the Institute, to be held at the Hollenden Hotel in Cleveland, are now nearing completion. The personnel of the various sub-committees of the Convention Committee mentioned in the PROCEEDINGS for April, is as follows:

Automobile Committee: L.P. Crecelius, Chairman, Allard Smith, M. E. Turner.

Banquet Committee: W. M. Skiff, Chairman, M. Luckiesh, L. B. Timmerman, I. H. Van Horn.

Finance Committee: Robert Lindsey, Chairman, A. N. Barron, S. E. Doane.

Golf Committee: G. S. Crane, Chairman, F. W. Ballard, John H. Finney.

Hotel and Boat Committee: E. W. P. Smith, Chairman, N. G. G. Lindstrom, C. W. Orr.

Inspection Trip Committee: S. L. Henderson, Chairman, F. M. Hibben, A. M. Lloyd.

Ladies Entertainment Committee: Norman Anderson, Chairman, A. M. MacCutcheon, A. S. McAllister, C. S. Ripley, H. L. Wallau.

Outing Committee: Geo. Miller, Chairman, C. L. Collins, E. J. Edwards, Farley Osgood.

Prize Committee: Geo. Milner, Chairman, B. W. David, H. Dingle.

Publicity Committee: H. B. Dates, Chairman, Chas. S. Howe, W. F. Johnson, E. P. Roberts, J. Franklin Stevens.

Reception Committee: E. P. Roberts, Chairman, Albert Allen, Chas. F. Brush, W. E. Davis, S. E. Doane, Chas. S. Howe, E. P. Hyde, J. C. Lincoln, E. H. Martindale, B. A. Stowe.

Tennis Committee: F. R. Fishback, Chairman, R. B. Chillas, H. Dingle.

Transportation Committee: Farley Osgood, Chairman, A. S. McAllister, J. Franklin Stevens.

The Meetings and Papers Committee has decided upon the following program of technical papers, which are given by sessions. The time to be allotted to the various technical sessions, together with the various entertainment features, will be published in detail in the June PROCEEDINGS.

INDUSTRIAL POWER SESSION.

Electric Drive for Reversing Rolling Mills, by Wilfred Sykes and David Hall.

Motor Equipment for the Recovery of Petroleum, by W. G. Taylor.

ELECTROPHYSICS SESSION.

Effect of High Continuous Voltages on Air, Oil and Solid Insulations, by F. W. Peek, Jr.

The Corona Voltmeter, by J. B. Whitehead and M. W. Pullen.

PROTECTIVE APPARATUS SESSION.

Studies in Lightning Protection on 4000-Volt Circuits, by D. W. Roper.

Experience in Recent Developments of Central Station Protective Features, by N. L. Pollard and J. T. Lawson.

Protection of High-Tension Distribution Systems by Isolating Transformers, by O. O. Rider.

Megger and other Tests on Suspension Insulators, by F. L. Hunt.

Experiences in Testing Porcelain Insulators, by E. E. F. Creighton.

New Method of Grading Suspension Insulators, by R. H. Marvin.

POWER TRANSMISSION SESSION.

Committee Report on the Effect of Altitude on Operating Temperature Rise.

Effect of Barometric Pressure on Temperature Rise of Self-Cooled Stationary Apparatus, by V. M. Montsinger.

Restoring Service After a Necessary Interruption, by F. E. Ricketts.

MISCELLANEOUS SESSION.

Theory of Parallel Grounded Wires and Production of High Frequency in Transmission Lines, by E. E. F. Creighton.

Application of a Polar Form of Complex Quantities to the Calculation of A-C. Phenomena, by N. S. Diamant.

MISCELLANEOUS SESSION.

Suggestions for Electrical Research in Engineering Colleges, by V. Karapetoff.

Tractive Resistances to a Motor Delivery Wagon on Different Roads and at Different Speeds, by A. E. Kennelly and O. R. Schurig.

PACIFIC COAST CONVENTION, SEATTLE, SEPTEMBER 5-8, 1916

Upon request of the Seattle Section and with the approval of all the other Pacific Coast Sections, the Board of Directors has authorized the annual Pacific Coast Convention to be held in Seattle, September 5th to 8th, under the auspices of the Seattle Section. Several committees have been appointed by the Seattle Section which are formulating plans for the forthcoming convention, and it is expected that the technical program and other details will be ready for announcement in an early issue of the PROCEEDINGS.

COMING SECTION MEETINGS

Denver.—May 27, 1916, University of Colorado, Boulder, Colo. Demonstration of artificial transmission line which will bring out the electrical characteristics of this transmission line both as regards the transmission of power and of telephone currents.

St. Louis.—May 10, 1916. Paper: "Protection of Buildings against Lightning," by Terrell Croft.

STATE DIRECTORS FOR INDUSTRIAL PREPAREDNESS COMMITTEE

The committee on industrial preparedness of the Naval Consulting Board of the United States has announced the names of those engineers and chemists who have agreed to serve as state directors of the organization for industrial preparedness. The state directors will also be associate members of the Naval Consulting Board.

As announced in the March, 1916, PROCEEDINGS, the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers and the American Chemical Society were requested by the President of the United States to nominate representatives from their membership, one from each society for each state in the Union, "for the purpose of assisting the Naval Consulting Board in the work of collecting data for use in organizing the manufacturing resources of the country for the public service in case of emergency."

The list of A. I. E. E. state directors is as follows:

Alabama—Theodore Swann, sales manager Alabama Power Company, Birmingham.

Alaska—Louis E. McCoy, power house superintendent, Treadwell Gold Mining Company, Juneau.

Arizona—David W. Jones, chief elec, trician Arizona Copper Company-Clifton.

Arkansas—W. N. Gladson, dean, College of Engineering, University of Arkansas, Fayetteville.

California—A. H. Babcock, consulting electrical engineer, Southern Pacific Company, San Francisco.

Colorado—W. S. Aldrich, associate professor of electrical engineering, Colorado Agricultural College, Fort Collins.

Connecticut—Samuel Ferguson, vice-president Hartford Electric Light Company.

Delaware—W. C. Spruance, Jr., E. I. Du Pont de Nemours & Company, Wilmington.

District of Columbia—John H. Finney, Southern manager Aluminum Company of America, Washington.

Florida—C. S. Hammatt, president Consolidated Engineering Company, Jacksonville.

Georgia—A. M. Schoen, chief engineer S. E. Underwriters' Association, Atlanta.

Idaho—O. G. F. Markhus, general superintendent Electric Investment Company, Boise.

Illinois—P. Junkersfeld, assistant to vice-president, Commonwealth Edison Co., Chicago.

Indiana—F. S. Hunting, vice-president and general manager Fort Wayne Electric Works of General Electric Company.

Iowa—Norman T. Wilcox, sales manager Mississippi River Power Company, Keokuk.

Kansas—George C. Shaad, professor of electrical engineering, University of Kansas, Lawrence.

Kentucky—Carl P. Nachod, president Nachod Signal Company, Louisville.

Louisiana—M. S. Sloan, general manager New Orleans Railway & Light Company.

Maine—W. S. Wyman, treasurer and general manager, Central Maine Power Co., Augusta.

Maryland—J. B. Whitehead, professor of electrical engineering, Johns Hopkins University, Baltimore.

Massachusetts—C. L. Edgar, president and general manager Edison Electric Illuminating Company of Boston.

Michigan—H. H. Crowell, president Michigan Railway Company, Grand Rapids.

Minnesota—William N. Ryerson, general manager and chief engineer, Great Northern Power Company, Duluth.

Mississippi—J. T. Robertson, secretary and electrical engineer, Mississippi Inspection & Advisory Rating Company, Vicksburg.

Missouri—Charles S. Ruffner, vice-president and general manager Electric Company of Missouri, St. Louis.

Montana—M. H. Gerry, Jr., president Engineering Corporation, Helena.

Nebraska—H. A. Holdredge, general manager Omaha Electric Light & Power Company.

Nevada—W. K. Freudenberger, chief engineer Public Service & Railroad Commissions of Nevada, Carson City.

New Hampshire—J. Brodie Smith, vice-president and general manager Manchester Traction, Light & Power Company.

New Jersey—Farley Osgood, assistant general manager, Public Service Electric Company, Newark.

New Mexico—J. L. Brenneman, professor of electrical engineering University of New Mexico, Albuquerque.

New York—William McClellan, consulting engineer, New York City.

North Carolina—Charles I. Burkholder, general manager, Southern Power Company, Charlotte.

North Dakota—John F. Stevens, assistant professor of electrical engineering, University of North Dakota, University.

Ohio—Samuel G. McMeen, president Ohio State Telephone Company, Columbus.

Oklahoma—H. V. Bozell, director school of electrical engineering, State University of Oklahoma, Norman.

Oregon—O. B. Coldwell, general superintendent, Portland Railway, Light & Power Company.

Pennsylvania—Paul Spencer, electrical engineer, United Gas & Improvement Company, Philadelphia.

Rhode Island—L. W. Downes, vice-president and general manager, D. & W. Fuse Company, Providence.

South Carolina—W. M. Riggs, president Clemson Agricultural College.

South Dakota—B. B. Brackett, professor of electrical engineering, South Dakota State College, Brookings.

Tennessee—F. G. Proutt, consulting engineer, Memphis.

Texas—Fred A. Jones, consulting engineer, Dallas.

Utah—Markham Cheever, chief engineer, Utah Power & Light Company, Salt Lake City.

Vermont—B. T. Burt, vice-president and general manager, Rutland Railway, Light & Power Company.

Virginia—Walter S. Rodman, associate professor of electrical engineering, University of Virginia.

Washington—John Harisberger, general superintendent, light and power department, Puget Sound Traction, Light & Power Company, Seattle.

West Virginia—H. S. Sands, president H. S. Sands Electric & Manufacturing Company, Wheeling.

Wisconsin—A. W. Berresford, vice-president and general manager, Cutler-Hammer Manufacturing Company, Milwaukee.

Wyoming—P. N. Nunn, president, Wyoming Electric Company, Casper.

CORRELATION OF THE MAGNETIC AND MECHANICAL PROPERTIES OF STEEL

The United States Bureau of Standards, Washington, D. C., has issued Scientific Paper No. 272, entitled "Correlation of the Magnetic and Mechanical Properties of Steel," which will be sent free to anyone interested in the subject, upon application to the Bureau of Standards.

So much work on this subject has been done during the last few years that the prospects are that the magnetic examination of steel will furnish information of practical value as to its fitness for mechanical uses, without at the same time injuring or destroying the specimen under test.

This paper is a review of the work done in correlating the magnetic and mechanical properties of steel. Among the mechanical properties that have been studied in connection with the magnetic characteristics are hardness, toughness, elasticity, tensile strength, and resistance to repeated stresses.

MEMBERSHIP COMMITTEE

The following figures show the number of applications for admission to the Institute received from the beginning of the fiscal year, May 1, 1915, to April 26, 1916, inclusive:

Sections	Applications Received May 1, 1915 to April 26, 1916.	Per Cent of Present Section Membership
Atlanta	6	13.5
Baltimore	7	7.5
Boston	17	4.5
Chicago	36	7.5
Cleveland	27	10.
Denver	27	57.
Detroit-Ann Arbor	9	7.
Fort Wayne	5	12.
Indianapolis-Lafayette	3	6.
Ithaca	5	8.
Los Angeles	6	4.
Lynn	6	6.
Madison	3	8.
Milwaukee	8	6.
Minnesota	2	2.
Panama	9	14.
Philadelphia	20	6.
Pittsburgh	47	11.
Pittsfield	7	4.5
Portland	3	3.5
Rochester	6	10.
St. Louis	18	14.5
San Francisco	22	7.8
Schenectady	39	11.
Seattle	10	12.5
Spokane	1	2.
Toledo	3	11.5
Toronto	10	6.5
Urbana	6	23.
Vancouver	2	3.
Washington, D. C.	9	10.
	379	

Total number of members located in Section territory		4211	
Percentage for Section territory			9%
Received from applicants outside Section territory	388		
Total number members outside Section territory		4009	
Percentage for outside territory			9%
Totals	767	8220	

MEETING IN NEW YORK, APRIL 14, 1916

The 320th meeting of the A. I. E. E. was held on the fifth floor of the Engineering Societies Building, New York, Friday, April 14, 1916. The meeting was called to order at 8:20 p.m. by President Carty, who stated that owing to the unavoidable absence of Mr.

Clarence Renshaw, who was in the South, his paper on "High-Voltage D-C. Railway Practise" would be read by Mr. N. W. Storer. The paper was then presented by Mr. Storer, who also showed a number of lantern slides illustrating the 5000-volt direct-current equipment described in Mr. Renshaw's paper. The paper called forth considerable discussion, which was participated in by Messrs. F. J. Sprague, W. J. Davis, Jr., W. B. Potter, Calvert Townley, S. I. Oesterreicher, B. F. Wood, E. V. Pannell, A. H. Armstrong, N. W. Storer, Carl Schwartz, and Selby Haar.

A. I. E. E. WASHINGTON MEETING, APRIL 26, 1916

The 321st meeting of the American Institute of Electrical Engineers was held at the New Willard Hotel, Washington, D. C., April 26, 1916, under the auspices of the Committee on Development of Water Power and the Washington Section of the Institute.

Two sessions were held, the first opening at 2:30 in the afternoon and the second in the evening at 8:15.

The afternoon session was called to order by Mr. R. H. Dalgleish, Chairman of the Washington Section, who made a short address of welcome to the members and guests and presented President John J. Carty, who presided. President Carty made a brief address in which he pointed out the wonderful achievements which have been accomplished in electrical engineering by members of the Institute and the important part which the Institute has been called upon to play in connection with various activities of the government. He stated that it could no longer be said with truth that the scientific men and engineers of the country are not taking the part in the public affairs of the nation which is expected of them in consequence of their special training and extensive experience.

The general subject of the meeting was "The Relation of Water Power to the Industrial Advancement of the Country," and at the afternoon session the three following papers were presented by their authors:

Electrochemical Industries and Their Interest in the Development of Water Powers, by Lawrence Addicks.

Water Power Development and the Food Problem, by Allerton S. Cushman.

The Relation of Water Power to Increased Transportation, by L. B. Stillwell.

These papers were discussed by the Hon. Thomas Ewing, Commissioner of Patents, D. B. Rushmore, F. A. Woodbury, Henry G. Stott, J. B. Whitehead, Gano Dunn, L. H. Baekeland, and the authors of the papers.

The evening session was called to order by President Carty and in the absence of Mr. W. R. Whitney his paper on "The Relation of Water Power to the National Defense" was read by Mr. John H. Finney of the Washington Section. This was followed by a paper by Mr. Gano Dunn on "The Water Power Situation, including its Financial Aspect." These papers were discussed by Messrs. F. A. Lidbury, Lawrence Addicks, L. H. Baekeland, C. G. Atwater, Calvert Townley, Congressman George R. Smith, of Minnesota, D. B. Rushmore, Oscar T. Crosby, and John H. Finney.

There were 250 members and guests of the Institute present at the meeting and the character of the papers and the high standing of the authors contributed to make this meeting a most successful and notable gathering.

DIRECTORS' MEETING, NEW YORK, APRIL 14, 1916

The Board of Directors held its regular monthly meeting in New York on Friday, April 14, 1916, at 3:30 p.m.

There were present: President John J. Carty, New York; Past-Presidents C. O. Mailloux, New York, and P. M. Lincoln, Pittsburgh, Pa.; Vice-Presidents N. W. Storer, Pittsburgh, Pa., Farley Osgood, Newark, N. J., C. A.

Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William McClellan, New York; Managers H. A. Lardner, San Francisco, Cal., P. Junkersfeld, Chicago, Ill., L. T. Robinson, Schenectady, N. Y., Frederick Bedell, Ithaca, N. Y., A. S. McAllister, New York, C. E. Skinner, Pittsburgh, Pa., John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $7,828.12 was ratified.

The report of the Board of Examiners of its meeting held on April 6 was read, and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners, 125 students were ordered enrolled, 87 applicants were elected to the grade of Associate, two applicants were elected to the grade of Member and two to the grade of Fellow, and four Associates were transferred to the grade of Member, in accordance with the lists printed elsewhere in this issue of the PROCEEDINGS.

Upon the petition of 31 Institute members, and with the approval of the Sections Committee, the organization of a Section of the A. I. E. E. in Kansas City, Mo., was authorized.

Upon the recommendation of the Sections Committee, a conference of the Student Branches at the Annual Convention, similar to the Section Delegates Conferences held each year, was authorized, but with the understanding that the Institute could not undertake to defray the transportation expenses of the Branch representatives. The appointment of an officer to preside at this conference was left to the Sections Committee.

Invitations were received and accepted to appoint one representative to attend the exercises in celebration of the 150th anniversary of the founding of Rutgers College, October 13-15, 1916, and one to attend the dedication ceremonies in connection with the opening of new buildings at the Massachusetts Institute of Technology, June 14, 1916.

A considerable amount of other business was transacted, reference to which will be found in this and future issues of the PROCEEDINGS.

PAST SECTION MEETINGS

Atlanta.—March 29, 1916, Chamber of Commerce Assembly Hall. Address by Mr. H. E. Bussey on "The Panama Canal." The address was illustrated by motion pictures and lantern slides. Invitations to this meeting were extended to the Affiliated Technical Societies of Atlanta. Attendance 348.

Baltimore.—March 10, 1916, Physical Laboratory, Johns Hopkins University. Paper: "Heavy Electric Traction," by J. F. Layng. Attendance 25.

Boston.—March 7, 1916, lecture room of the Franklin Union. Prof. C. L. Dawes and Mr. H. G. Crane gave a lecture and demonstration on "The Oscillograph." Attendance 100.

April 4, 1916, auditorium of the Franklin Union. Illustrated address by Mr. W. C. Bamberg on "The Telephone." Motion pictures of applications of electricity.

Chicago.—March 27, 1916. Subject: Electric Vehicles. Papers (1) "Automobile Motor Characteristics," by F. A. Putt; (2) "Accomplishments of the Electric Passenger Car," by Gail Reed; (3) "The Electric Commercial Vehicle," by W. J. McDowell. Attendance 85.

Cleveland.—March 20, 1916, Chamber of Commerce. Papers: (1) "Cleveland Ornamental White-Way Street Lighting," by C. G. Beckwith; (2) "Transformer Design," by Ward Harrison; (3) "Lighting Unit," by G. A. Thornton. Attendance 56.

Denver.—March 18, 1916, Denver Athletic Club. Paper: "Some Telephone Problems, Past and Present," by Robert B. Bonney. Inspection trip through main telephone exchange of the

Mountain States Telephone and Telegraph Company. Attendance 41.

Detroit-Ann Arbor.—March 10, 1916, Detroit Engineering Society Hall. Paper: " The Electric Furnace," by E. L. Crosby. Attendance 60.

Indianapolis-Lafayette.—March 17, 1916, Indianapolis. Paper: " The Electrification of the Bedford Stone District," by D. J. Angus. Attendance 98.

Ithaca.—March 25, 1916, Cascadilla Cafeteria, Cornell University. Ninth Annual Banquet of Ithaca Section. Addresses by President J. J. Carty, Hon. Frank Irvine, Dean W. P. Graham and Prof. Alexander Gray. Attendance 100.

Los Angeles.—March 21, 1916, Chamber of Commerce Building. Paper: " The Relation of Electrical Engineering to the Problems of the Mt. Wilson Solar Observatory," by Arthur F. King. Attendance 48.

Lynn.—March 1, 1916, General Electric Works, West Lynn. Lecture by Dr. M. Luckiesh on " Light, Shade and Color in Illumination." Demonstration with the aid of large installation of apparatus of the effects of lights of different colors on statuary, paintings, etc., also experiments showing mixing of colors. Attendance 108.

April 5, 1916, General Electric Co., Center Street, Lynn. Illustrated lecture by Mr. Lewis E. Underwood on " Progress in the Art of Motor Design and Manufacture." Attendance 285.

Milwaukee.—March 21, 1916, Plankinton Hall, auditorium. Illustrated address by Dr. John A. Brashear on " The Great Telescopes of the World and Discoveries Made by Their Use." Attendance 600.

April 12, 1916, Republican House. Illustrated address by Mr. John A. Dienner on " The U. S. Patent Office." Attendance 60.

Panama.—March 26, 1916, Cristobal Coaling Plant. Inspection trip through the Cristobal Coaling Plant. Attendance 56.

Pittsburgh.—March 14, 1916. Paper: " Constant-Current Systems for Series Street Lighting," by W. R. Woodward. Joint meeting with Pittsburgh Section of Illuminating Engineering Society. Attendance 64.

April 11, 1916. Paper: " Storage Battery Locomotives and Their Applications," by J. G. Carroll. Attendance 76.

Pittsfield.—Hotel Wendell. Paper: " The Gyroscope and Some of Its Applications," by H. L. Tanner. Paper was illustrated with lantern slides and working models of the gyroscope. Attendance 96.

Rochester.—March 24, 1916, rooms of Rochester Engineering Society. Paper: " Notes on the Construction of Medium Size Direct-Current Motors," by Edward F. Davison and E. Darwin Smith, Jr. Attendance 40.

Schenectady.—March 21, 1916, Edison Club Hall. Illustrated address by Dr. Albert C. Crehore on " Atoms and Molecules." Attendance 225.

April 18, 1916, Edison Club Hall. Paper: " Railway Electrifications," by W. B. Potter. Paper was illustrated by lantern slides. Attendance 400.

Seattle.—March 21, 1916, Central Building. Paper: " A Fixed Standard of Capacity and Methods of Comparing Capacities," by P. D. Naugle. Attendance 28.

Spokane.—March 17, 1916, Washington Water Power Bldg. Papers: (1) " Every-day Line Calculations," by Prof. H. V. Carpenter; (2) " The Organization and Duties of the Engineering Corps of the Army," by Lieut Winton. Attendance 44.

St. Louis.—April 12, 1916, Engineers Club. Paper: " Railroad Day and Night Signals," by B. H. Mann. Attendance 75.

Toledo.—Toledo University. Paper: " Electromagnets," by Arthur Simon. Demonstration of d-c. and a-c. magnets, solenoids and switches, also lantern slides showing magnets and their applications. Attendance 40.

Washington.—March 7, 1916, Cosmos Club. Papers: (1) " Rail Joints and Bonds," by C. E. Gardiner; (2) " Difficulties in Photometry of Lights of Different Colors." Attendance 45.

PAST BRANCH MEETINGS

University of Arkansas.—March 21, 1916, Fayetteville. Papers: (1) " Wireless Detectors," by H. A. Brown; (2) " Chicago Central Station Institute," by D. C. Hopper. Attendance 12.

April 4, 1916. Discussion on " Proposals for Various Prime Movers." Attendance 8.

Brooklyn Polytechnic Institute. April 1, 1916. Inspection trip to the service plant of the Pennsylvania Railroad Company, Seventh Avenue and Thirty-Third Street, New York. Attendance 20.

University of California.—Paper: "X-Rays," by E. C. Woodruff. Attendance 26.

March 30, 1916. Paper: (1) " Railroad Signals," by Mr. Reynolds; (2) " The Scientific Man," by Mr. Johnson. Attendance 29.

Clarkson College of Technology.—March 22, 1916. Address by Prof. Paul Cloke on " Lightning Arresters." Attendance 17.

April 5, 1916. Papers: (1) " Design and Construction of Commutators "; (2) " Heating by Exhaust Steam "; (3) " Construction and Operation of Searchlights." Attendance 14.

Colorado State Agricultural College. April 11, 1916. Motion pictures on " The Steam Turbine, and Works of the General Electric Company." Attendance 28.

University of Colorado.—April 13, 1916, Hale Scientific Building. Paper: " Some Popular Misconceptions of the Street Railway Business," by H. C. Kendall. Attendance 25.

Georgia School of Technology.—March 14, 1916, Electrical Building. Address on " Telephone Transmission." Attendance 33.

Highland Park College.—April 12, 1916, Electrical Engineering Laboratory. Two lectures by Dr. W. S. Franklin; one in the afternoon on " Some Mechanical Analogies in Electricity and Magnetism," and another in the evening on " Bill's School and Mine." Attendance 150.

Kansas University.—March 23, 1916, Marvin Hall. Motion pictures of the Pittsfield shops of the General Electric Company. Attendance 35.

April 3, 1916, Marvin Hall. Illustrated lecture on " Hydraulic Power Development," read by Prof. J. O. Jones. Attendance 27.

Kansas State Agricultural College.—March 16, 1916. Address by Mr. H. M. Biebel on " Reminiscences of an Engineer." Attendance 35.

University of Kentucky.—April 5, 1916, Mechanical Hall. Lecture by Mr. Breckenridge on " From Ore to Finished National Pipe." Lecture was illustrated with motion pictures. Joint meeting of A. I. E. E. and A. S. M. E. Branches. Attendance 84.

Lafayette College.—February 28, 1916, Pardee Hall. Papers: (1) " The Butte, Anaconda and Pacific Electrification "; (2) " Insulator Testing." Attendance 24.

March 6, 1916. Papers: (1) " Properties of Electrolytic Iron Melted in a Vacuum "; (2) " A Year's Progress in Electrical Engineering." Attendance 19.

March 13, 1916. Papers: (1) " Lightning and Lightning Protection "; (2) " Aluminum Lightning Arresters." Attendance 22.

March 20, 1916. Paper: " The Edison Storage Battery." Attendance 23.

Lehigh University.—March 30, 1916. Papers: (1) " Multi-Unit Control of Railway Motors," by J. F. Wentz; (2) " The Naval Consulting Board," by Joseph Richards. Attendance 44.

April 14, 1916, Physics Laboratory. Papers: (1) " The Gas Turbine," by David R. Brobst; (2) " The Mercury Motor Watt-Hour Meter," by Scott Lynn. Attendance 41.

University of Michigan.—March 24, 1916, New Engineering Building. Electrical first aid and demonstration of the pulmotor, by Dr. C. B. Stouffer. Attendance 187.

March 31, 1916. Paper: "Central Stations," by Guy W. Lunn. Paper illustrated with lantern slides. Attendance 70.

North Carolina College of Agricultural and Mechanical Arts.—March 15, 1916. Illustrated lecture by Messrs. E. A. Hester and L. O. Henry on "Wiring Our Homes." Attendance 22.

March 22, 1916. Addresses as follows—"Evolution of Wireless Telegraphy," by T. H. Holmes; "Torpedoes," by E. P. Holmes. Attendance 18.

April 5, 1916. Demonstration of the "Talking Arc," by F. W. Proctor, assisted by T. L. Millwee and J. B. Robinson. Mr. R. M. Hooper then read an article on "Electric Trucks." Attendance 21.

University of North Carolina.—March 17, 1916, Electrical Engineering Laboratory. Election of officers as follows—chairman, Edward Yates Keesler; secretary, William Henry Joyner. Attendance 7.

March 31, 1916, Chemistry Building. Paper: "Inventories; Practical Work in Connection with Philadelphia Electric Company," by E. I. Staples. Attendance 15.

April 15, 1916, Alumni Building. Papers: (1) "Electric Drive in Rolling Mills," (2) "Southern Power Company." Attendance 12.

Ohio Northern University.—March 22, 1916, Dukes Memorial. Addresses as follows—"Radioactivity," by Prof. F. A. Berger; "Street Lighting," by Mr. R. D. Iden. Attendance 19.

April 5, 1916. Papers: (1) "Telephone vs. Telegraph for Railway Communication," by Mr. Brockman; (2) "Solenoids," by Mr. Bedell. Attendance 20.

Address on "The Necessary Change in the Old Carbon Incandescent Lamp Shade to Suit the New Mazda Lamps," by W. M. Holmes. Attendance 30.

Oregon Agricultural College.—March 16, 1916. Paper: "Public Utility Economies," by L. A. McArthur. Attendance 22.

March 30, 1916. Paper: "High-Tension Measuring Instruments," by Chas. E. Oakes. Attendance 15.

Pennsylvania State College.—February 16, 1916, Engineering Club Room. Election of officers as follows—president, C. L. Knotts; vice-president, J. B. Kelly; secretary, Wm. W. Herold, Jr.; treasurer, L. E. Markle; sergeant-at-arms, T. F. Reimer. Attendance 35.

March 15, 1916, Engineering Club Room. Address by Mr. J. W. Dietz on "What Modern Business Demands of the College Man." Attendance 41.

Purdue.—March 7, 1916, Electrical Engineering Building. Paper: "The Modern Attack on the Lighting Problem," by E. P. Hyde. Attendance 180.

March 21, 1916. Paper: "Watt-Hour Meters," by G. M. Torzillo. Attendance 55.

Rhode Island State College.—March 8, 1916, Science Hall. Illustrated address by Mr. C. E. Seifert on "Recent Electric Power Developments." Attendance 21.

Syracuse University.—March 16, 1916. Paper: "Aluminum," by L. W. Gay. Attendance 11.

March 30, 1916. Paper: "Electric Service in the Home," by E. H. Sheahan. Attendance 15.

April 6, 1916. Paper: "Problem of the Big Creek Development," by W. R. Dwyer. Attendance 14.

April 13, 1916. Paper: "High-Voltage D-C. Railway Practise." Attendance 14.

Throop College of Technology.—March 21, 1916. Pasadena Hall. Illustrated address by Mr. Barre on "The Big Creek Hydroelectric Development." Attendance 61.

Virginia Polytechnic Institute.—March 22, 1916. Illustrated lecture on "Illumination." Attendance 75.

Washington University.—February 17, 1916. Illustrated lecture by Mr. James L. Hamilton on "Motors." Attendance 30.

March 30, 1916. Paper: "Some Experiences in the Operation of a Large Electric Light and Power Company," by H. W. Eales. Attendance 28.

Washington State College.—January 28, 1916, Mechanic Arts Building. Election of officers as follows—president John Gene; vice-president, C. A. Worthen; treasurer, C. Jensen; secretary, C. J. Melrose. Attendance 15.

February 18, 1916. Paper: "The Engineering Courses of the College," by Prof. Akers. Attendance 11.

March 17, 1916. Address by Mr. Melvin entitled "A Student at the General Electric Company." Attendance 21.

March 27, 1916. Illustrated address by Mr. Fred Wheeler on "Dredge Mining in Alaska." Attendance 28.

University of Washington—March 7, 1916, Forestry Building. Paper: "Illumination," by C. Hill. Illustrated address on "The Westinghouse Students Course," by Geo. Tripple. Attendance 46.

Worcester Polytechnic Institute.—March 17, 1916, Electrical Engineering Building. Illustrated lecture by Mr. W. R. Bell, on "The System of the Connecticut River Transmission Company." Attendance 42.

Yale University.—March 31, 1916, Electrical Engineering Laboratory. Papers: (1) "Transmission Systems for Automobiles," by W. B. Hall; (2) "The Owen Magnetic Transmission System," by D. F. Seacord; (3) "Development of Telephone Systems," by J. G. Van Santvoord; (4) "Hydroelectric Power Houses," by A. W. Cahoon. Attendance 75.

PERSONAL

MR. SYDNEY O. SWENSON has become a member of the Engineering Offices of Putnam A. Bates.

WILLIAM J. NORTON, PAUL P. BIRD and EZRA B. WHITMAN announce that they have formed a co-partnership and will engage in general engineering practise under the firm name of Norton, Bird and Whitman.

MR. GEORGE W. MARTIN and MR. JAY GRANT DE REMER have announced the organization of an engineering firm with offices at 100 Broadway, New York, for general practise in public utilities and industrial plants.

MR. REID JONES has formed a partnership with C. S. THOMAS, JR. of St. Louis. Their firm, Thomas & Jones, is under contract to construct the new $1,750,000 terminals for the M. K. & T. R.R. at San Antonio.

OBITUARY

DR. ERIC GERARD, of Liège, Belgium, one of the best-known professors of electrical engineering in the world, and president of the Belgian National Committee of the International Electrotechnical Commission, died in Paris on March 27, 1916. Dr. Gerard was in Petrograd when the war broke out, and since then had lived in London and Paris. Eric Gerard was born in Liège September 22, 1856, and was graduated from the School of Mines in that city in 1878. Entering the Belgium Telegraph Department, he was sent to Paris for further study. He returned to Liège as secretary of the Belgian section of the exposition in 1881, and in the same year was appointed secretary of the International Congress on Electrical Units. He succeeded Professor De Large in the chair of telegraphy and other applications of electricity in the School of Mines at Liège, and when Senator Montefiore founded, in 1883, the Institut Electrotechnique Mont-

fiore in Liège, Dr. Gerard was chosen as its director, and occupied that post up to the time of his death. He organized its laboratories and devised many electrical instruments and methods of measurement, and was the very first teacher of electrical engineering in the world, as this was the first educational institution to give courses in electrotechnics. Dr. Gerard later became a member of the faculty of the University of Liège, and was also inspector-general of telegraphs for Belgium. He was the Belgian representative to the Electrical Congress in Chicago in 1893 in connection with the exposition, and on his subsequent tour of this country made many friends among American engineers and scientists. He was also a delegate at Paris in 1900. Dr. Gerard was one of the founders of the International Electrotechnical Commission. He was a prolific writer on technical subjects, which he handled with especial clearness and literary skill.

George Herbert Stockbridge, patent attorney of New York, chairman of the Law Committee of the Institute, died in New York April 26, 1916. Mr. Stockbridge was born in Mexico, Maine, in 1852. He was graduated from Bates College, and then took a postgraduate course of three years at the University of Leipzig. He became an instructor at John Hopkins University and later at Amherst College. Mr. Stockbridge then entered the United States Patent Office, where he became chief electrical examiner. While engaged in this work he studied law and was admitted to the bar. He practised in Washington, and in 1898 came to New York as counsel for the Westinghouse interests. For the last three years he had been the legal adviser of the Cooper Hewitt Electric Company. Mr. Stockbridge employed much of his leisure in literary pursuits, and had published verse and was a contributor to leading magazines. He was elected an Associate of the Institute May 24, 1887.

RECOMMENDED FOR TRANSFER, APRIL 6, 1916

The Board of Examiners, at its regular monthly meeting on April 6, 1916, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To the Grade of Member

Chandler, William A., Electrical Engineer, H. C. Frick Coke Co., Bunsen Coal Co., Scottdale, Pa.

Dean, Peter P., Consulting Engineer, New York, N. Y.

Hedges, George L., Engineer, Kelman Electric & Mfg. Co., Los Angeles, Cal.

Hoen, W. M., General Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Ingerslev, Kay, Electrical Engineer, c/o Siam Electricity Co. Ltd., Bangkok, Siam.

Pigott, R. J. S., Power Supt., Remington Arms and Ammunition Co., Bridgeport, Conn.

Sessions, Frank L., Consulting Engineer, Cleveland, Ohio.

Shepherd, Claude R., Electrical Engineer in charge, Commissioners of Lincoln Park, Chicago, Ill.

Smith, E. W. P., City Electrician, Cleveland, Ohio.

Waller, Alfred E., Production Manager, Ward Leonard Electric Co., Bronxville, N. Y.

FELLOWS ELECTED APRIL 14, 1916

Bosson, Frederick N., Electrical Engineer, Calumet & Hecla Mining Co., Calumet, Mich.

Lenz, Charles Otto, Consulting Engineer, 120 Broadway, New York, N. Y.

TRANSFERRED TO THE GRADE OF MEMBER APRIL 14, 1916

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on April 14, 1916.

BUSWELL, JAMES M., General Manager, San Joaquin Light & Power Corp., Fresno, Cal.

KINGSBURY, JOHN MCLEAN, Electrical Engineer, Secretary and Treasurer, Kingsbury, Gas Electric Motor Car Co., New York, N. Y.

PEASLEE, W. D., Consulting Engineer, Portland, Ore.

PRICE, JOHN B., Price Electric & Machinery Co., Richmond, Va.

MEMBERS ELECTED APRIL 14, 1916

BARTLETT, LAWRENCE, Electrical Engineer, Denver Gas & Electric Light Co., Denver, Colo.

HAMMOND, JOHN HAYS, JR., Inventor, Gloucester, Mass.

ASSOCIATES ELECTED APRIL 14, 1916

AMES, GEORGE BETTON, Telephone Engineer, Railroad Commission of the State of Florida, Tallahassee, Fla.

ANDREWS, JOHN KENDIG, Assistant, Transformer Testing Dept., General Electric Co.; res., 184 Second St., Pittsfield, Mass.

*ARMSTRONG, GELSTON HILLS, Switchboard Draftsman, Duquesne Light Co., Pittsburgh; res., 516 Holmes St., Wilkinsburg, Pa.

BEAUFORE, WILLIAM COLBURN, District Sales Manager, Economy Fuse & Mfg. Co., 1406 Majestic Building, Detroit, Mich.

BEEBE, GEORGE L., Electrician, Wolverine Portland Cement Co., 15 West Pearl St., Coldwater, Mich.

BOOTH, WILLIAM KURTZ, Vice-President and Treasurer, Snyder Electric Furnace Co., 53 W. Jackson Blvd., Chicago, Ill.

BOULDIN, WILLIAM K., Transformer Inspector, Norfolk & Western Ry. Co., Coopers; res., Bromwell, W. Va.

BRADFORD, CHARLES COZAD, Sales Manager, U. S. Light & Heat Corp., Niagara Falls, N. Y.

*BROWN, HUGH ALEXANDER, Instructor in Electrical Engineering, University of Arkansas; res., 420 College Ave., Fayetteville, Ark.

BROWN, LLEWELLYN HOLMES, Secretary & Treasurer, Davis-Brown Electric Co ; res., 201 Pleasant St., Ithaca, N. Y.

BROWN, WILLIAM STEPHEN, Graduate Engineering Student, Johns Hopkins University; res., 222 W. Lafayette Ave., Baltimore, Md.

CANADY, DONALD RAY, Moving Picture Operator and Electrician, Metropolitan Theatre Co.; res., 10119 Detroit Ave., Cleveland, Ohio.

CANDEE, ANDREW HALEY, Railway Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh; res., 509 N. Euclid Ave., Pittsburgh, Pa.

CARPENTER, EDWARD S., Superintendent of Meters, Central Illinois Utilities Co., Gilman, Ill.

COMMENTZ, CHRIS A., Foreman of Motor Installation, Braden Copper Co., Rancagua, Chile, South America.

*COOPER, SIDNEY BRUCE, General Engineering Div., Railway Section, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1010 Rebecca Ave., Wilkinsburg, Pa.

COOPER, WALTER H., Operator, Jordan Plant, Pacific Power Co , Mono Lake, Cal.

CURREN, ARTHUR J., Secretary-Treasurer and Manager, Elyria Telephone Co.; res., 216 Washington Ave., Elyria, Ohio.

*DARROW, LEO HARVEY, Engineering Dept., American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

DAVIS, DONALD G., Student, Stevens Institute of Technology; res., Castle Stevens, Hoboken, N. J.

DAVIS, RANSOM FLOYD, Electrical Engineer, Acme Cement Plaster Co., Acme, Texas.

DEANE, LINDLEY EARL, Salesman and Traveling Engineer, American Enameled Magnet Wire Co., Muskegon, Mich.

*DEARBORN, RICHARD JEWELL, Patent Lawyer with E. W. Marshall, 76 William St., New York, N. Y.

DERRY, HERBERT GLENN, Collector, Mountain States Telephone & Telegraph Co.; res., Y. M. C. A., Denver, Colo.

EMERSON, ALBERT THEODORE, Powerman, Pacific Tel. & Tel. Co.; res., 1770 W. 62nd St., Seattle, Wash.

FINKS, G. H., Chief Electrician, Gilliam Coal & Coke Co., Arlington Coal & Coke Co., Shawnee Coal & Coke Co., & Glen Alum Coal Co., Gilliam, W. Va.

FINNEY, JOSEPH RAY, Electrical Engineer, Duquesne Light Co., Pittsburgh; res., 19 Harrison St., Crafton, Pa.

FORMAN, ALEXANDER HARDIE, Assistant Professor of Electrical and Exp. Engineering, West Virginia University, Morgantown, W. Va.

FORTIN, PAUL ROBERT, Electrical Engineer, Switchboard Engineering Dept., General Electric Co.; res., 233 Union St., Schenectady, N. Y

*FULK, CHARLES MADISON, Direct Current Design, General Electric Co.; res., 17 Alvey St., Schenectady, N. Y.

GALLAGHER, H. J., Sales Agent, General Electric Co., Rialto Building, San Francisco, Cal.

*GERARD, HARLEY JAMES AARON, Assistant Engineer, East St. Louis & Suburban Railway Co., 7 Collinsville Ave., East St. Louis, Ill.

GIFFORD, WALTER S., Statistician, American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

GILLETTE, GEORGE, Claim Agent, Tide Water Power Co., Wilmington, N. C.

GROFF, FREDERICK A., Assistant Engineer, N. Y. Municipal Railway Corp.; res., 947 E. 34th St., Brooklyn, N. Y.

HALL, ARTHUR JOHN, Railway Control Engineer, Railway Eng'g. Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 200 Mifflin Ave., Wilkinsburg, Pa.

HALLIDAY, T. W., Engineer, Rupert Electric Co., Rupert, Idaho.

HANSSON, AXEL SIGFRID, Chief Engineer, Schneider & Cie., Champagne s. Seine, France.

HARDY, GEORGE E., Meter Inspector, S. & E. L. Ry. & Lt. Co.; res., 309 Hill Ave., Steubenville, Ohio.

*HARE, KENNETH ROSS, Associate Editor, *Railway Electrical Engineer*, Room 2226, Woolworth Building, New York, N. Y.

HAWK, LESLIE LEWIS, Test and Engineering, Lincoln Electric Co.; res., 7102 Carnegie Ave., Cleveland, O.

HINTERPOHL, ARTHUR R. F., 425 West 146th St., New York, N. Y.

*JAIN, RANJIT SINGH, Assistant Engineer, Reliance Electric & Engineering Co., Cleveland, Ohio.

JENNINGS, FRANCIS RICHARD, F. R. Jennings Co., 214 Free Press Building, Detroit, Mich.

JOHNSON, WILLIAM MOORE, JR., Instructor, Bliss Electrical School, Takoma Park, Washington, D. C.

KAWAKITA, YOSHIO, President, Kawakita Electric Scheme Co., Ltd., Osaka, Japan.

KINARD, CLARENCE ALONZO, Superintendent of Meters, Westfield Gas and Electric Light Works; res., 105 Elm St., Westfield, Mass.

*KNEISLY, HARRY LOREN, Resident Engineer, Texas Power & Light Co., Temple, Texas; res., 123 S. Plum St., Troy, Ohio.

KOPP, OTTMAR HUGO, Telephone Engineer, Western Electric Co., 463 West St., New York, N. Y.

*KUNSE, ROBERT MARKLEY, Sales Engineer, Ft. Wayne Works, General Electric Co.; res., 2611 Broadway, Ft. Wayne, Ind.

LEISENRING, JOHN, Signal Engineer, Illinois Traction Co., Springfield, Ill.

LETTS, LOUIS WILFRED GEORGE, Electrical Engineer and Partner, Opotiki Electrical Installation, Richard St., Opotiki, Bay of Plenty, New Zealand.

LEWIS, RALPH ARNOLD, District Sales Manager, Edison Lamp Works of General Electric Co., 927-937 First National Bank Bldg., Denver, Colo.

LUECKE, FRED H., Superintendent of Lines, Central Illinois Utilities Co., Gilman, Ill.

LYNN, EWING KENNEDY, JR., Draftsman, Westinghouse Electric & Mfg. Co., East Pittsburgh; res., East McKeesport, Pa.

MAC DONALD, DANIEL F., Electrical Engineer, Degnon Co.; res., 80 Morton St., New York, N. Y.

MALMGREN, AR HUR GEORGE, Electrical Engineering Dept., Acme Wire Co.; res., 185 Mansfield St., New Haven, Conn.

MAXFIELD, LEWIS SANFORD, Electrical Draftsman, Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

*MCROBBIE, HENRY WILLIAM, 2121 E. Cherry St., Seattle, Wash.

MILLAR, WILLIAM ROBERTSON, Borough Electrical Engineer, Eyre St., Feilding, New Zealand.

MONROE, EDWIN AUGUSTUS, Electrician, Independent Electric Machinery Co.; res., 3712 Flora Ave., Kansas City, Mo.

MORRIS, RAY M., District Manager, Mountain States Tel. & Tel. Co., Durango, Colo.

NAU, PAUL BURTON, Superintendent, Meter Dept., Municipal Electric Light Department, Cleveland; res., 24 Wadena St., East Cleveland, O.

*PACKMAN, MORRIS EARL, Instructor of Radio Engineering, Dodge's Institute of Telegraphy, Valparaiso, Ind.

POHLMAN, CARL FREDERICK, Assistant Engineer, Central Union Telephone Co., Indianapolis, Ind.

PRICE, MILTON N., Engineering Dept., Chesapeake and Potomac Telephone Co.; res., 1718 Ashland Ave., Baltimore, Md.

RUGHEIMER, RALPH REINHARDT, Sales Engineer, Westinghouse Electric & Mfg. Co., Kelley-Moyer Bldg., Bluefield, W. Va.

RUSSELL, HERBERT S., Electrical Engineer, Denver Gas and Electric Light Co., Denver, Colo.

RYAN, WILLIAM J., Electrical and Steam Engineer, Toronto Hydro-Electric System; res., 1362 King St. West, Toronto, Ontario.

*SHU, SAWLAND J., Director, Waterways Engineering College, Nanking, China.

SIMPSON, RICHARD ERSKINE, Engineer, Travelers Insurance Co., Hartford, Conn.

SLAUSON, HENRY LEWIS, JR., Electrical Engineer and Electrical Draftsman, Duquesne Works, Carnegie Steel Co., Duquesne; res., 506 Kelly Ave., Wilkinsburg, Pa.

*SPRAY, LYNN WHITCOMB, In Charge of Small Motors Experimental Test, Ft. Wayne Works, General Electric Co.; res., 1214 W. Jefferson St., Ft. Wayne, Ind.

STEPHENS, BENJAMIN GEORGE CLAUDE, Electrical Engineer of Otago Office, National Electrical & Engineering Co., Dunedin, N. Z.

STEPHENSON, HERBERT ARMSTRONG, Chief Electrician, E. S. Stephenson & Co.; res., 111 Orange St., St. John, N. B., Canada.

STIGANT, STANLEY AUSTEN, Draughtsman, British Westinghouse Co., Trafford Park, Manchester, England.

STONE, DONALD DWIGHT, Automobile Electric Equipment, Engineering Dept., Buick Motor Co.; res., 514 East St., Flint, Mich.

TEMPLER, GUY MERSON, Powerhouse Superintendent, Hawera Electric Co., Powerhouse, Normanby, Taranaki, New Zealand.

THIELE, ERNEST A., Electrical Engineer, Central New England R. R. Co., Maybrook, N. Y.

UMANSKY, LEONID A., Member of Russian Imperial Artillery Commission; res., 2 Lowell Road, Schenectady, N. Y.

Wade, M. Leighton, City Engineer, City Hall, Duncan, B. C., Canada.

Wahlberg, Nils J. A., Railway Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Ward, Charles Wilson, Superintendent of Laboratory, Duquesne Light Co., 3708 5th Ave., Pittsburgh, Pa.

Waters, William Alexander, Electrical Engineer, National Electrical & Engineering Co. Ltd., Whangarei, New Zealand.

Werner, Peter L., Chief Electrician, Pittsburgh Steel Foundry Co., Glassport; res., 1130 Market St., McKeesport, Pa.

Whittaker, Charles Clarence, Railway Engineering Div., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 916 Ross Ave., Wilkinsburg, Pa.

Wilson, Charles Edwin, Erecting Engineer, Construction Dept., General Electric Co., Schenectady, N. Y.

Total 87.

*Former enrolled Students.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before May 31, 1916.

Anderson, S. W., Lexington, Va.
Armstrong, F. W., London, England.
Arthur, M. W., Cincinnati, O.
Atwood, J. A., Dayton, O.
Baldwin, H. S. (Member), West Lynn, Mass.
Baylor, A.K.(Member), New York,N.Y.
Bennett, A. C., East Pittsburgh, Pa.
Billings, W.C. (Member), Portland, Me.
Boult, J, B., Sault Ste. Marie, Mich.
Brehm, C. G., Oliver, Pa.
Brown, G. F., Winnipeg, Man.
Brown, R. E., Chicago, Ill.
Burgess, H. R., Cleveland, O.
Burnett, J. H.,New York, N. Y.
Carroll, M. B., Lynn, Mass.
Chapman, A. G., New York, N. Y.
Cobb, F. C., Newark, N. J.
Collopy, J. P., Scottsbluff, Nebr.
Cook, W. S., Hamilton, Ontario.
Crosby, L. S., Atlanta, Ga.
Danko, J. P., Brooklyn, N. Y.
Davison, V. A., New York, N.Y.
Dickey, W. H., Cleveland, O.
Doyle, A. J., New York, N. Y.
Drake, A. W., New York, N. Y.
Fairley, G. E. A., Baltimore, Md.
Fuchs, J. O., Poughkeepsie, N. Y.
Goddard, R. W., State College, N. M.
Gordon, C. P., Seattle, Wash.
Gordon, W. G., (Fellow), Toronto, Ont.
Gorman, H. P., New York, N. Y.
Gray, C. H., McKeesport, Pa.
Grayson, A. C., Newark, N. J.
Haley, H. S., San Francisco, Cal.
Harbold, C. E., Aurora, Nev.
Herrick, D. C., Cleveland, O.
Hines, B. F., Hattiesburg, Miss.
Holding, H.H. (Member), Newark, N. J.
Hovelson, H., Minneapolis, Minn.
Howk, C. L., New York, N. Y.
Jenney, L. R., New York, N. Y.
Johnson ,H. B., New Orleans, La.
Keyes, J. J., East Pittsburgh, Pa.
Kimball, A. L., Seattle, Wash.
Kirsten, F. K., Seattle, Wash.
Kohloss, F. H., City Point, Va.
Kuehn, N. L., Milwaukee, Wis.
Legier, E. W., Lynn, Mass.
Leibfried, W., New York, N. Y.
Lindsay, H. B., Annapolis, Md.
Lloyd, J. H., Panama, R. P.
Luft, O. L., St. Louis, Mo.
Mackay, W. J., Seattle, Wash.
Markley, F. R., East Pittsburgh, Pa.
McCarty, R. A., East Pittsburgh, Pa.
McWilliams, M., Dunedin, N. Z.
Mead, C. A., East Pittsburgh, Pa.
Miller, T. G., Chicago, Ill.
Morelli, E. (Member), Turin, Italy.
Moren, W. H., Vasteras, Sweden.
Murray, J. B., Brooklyn, N. Y.
Ober, D. C., Cleveland ,O.

Octavio, A. M., Rio de Janeiro, Brazil.
O'Hara, D. G., New York, N. Y.
Paine, N. D., Kenogami, Que.
Puppe, F. W., Chuquicamata, Chile.
Reuben, J., Bangalore, India.
Richardson, E. H., (Fellow), Ontario, Cal.
Rickard, E. B., Terre Haute, Ind.
Ricketts, F. E., Baltimore, Md.
Romanovsky, C., Schenectady, N. Y.
Saenz de Calahorra, A., New York, N.Y.
Smith, E. A., New York, N. Y.
Soule, H. C., East Pittsburgh, Pa.
Sparling, E. C., London, England.
Spasoff, San Rafael, Cal.
Stevenson, F. A., New York, N. Y.
Stimson, H. B., New York, N. Y.
Stoneman, E. C. R., Montreal, Que.
Stuckeman, W. F., Pittsburgh, Pa.
Sturge, J. H., Trenton, N. J.
Telfer, L. H., Wellington, Wash..
Thistlewhite, R., New York, N. Y.
Thornton, F. L., Kansas City, Mo.
Torrance, J. J., New York, N. Y.
Torrey, W. A., Avoca, Iowa.
Turnock, H. C., Cleveland, O.
Ulrich, B. H., Newark, N. J.
Urla, R. R., New York, N. Y.
Weller, E., New York, N. Y.
Whiting, L. R., Detroit, Mich.
Williams, H. K., Cleveland, O.
Wilson, J. M., New York, N. Y.
Wooll, J. H., San Francisco, Cal.
Wurts, T. C., East Pittsburgh, Pa.
Total 95.

STUDENTS ENROLLED APRIL 14, 1916

8011 Flores, O., Drexel Institute.
8012 Kusner, L., Drexel Institute.
8013 Bower, W. C., Drexel Institute.
8014 Ford, F. R., Drexel Institute.
8015 Hurwitz, J. L., Drexel Institute.
8016 Snow, A. T., Drexel Institute.
8017 Sutton, G. G., Va. Poly Inst.
8018 Meadows, S. R., Univ. of Utah.
8019 Bennett, T. E., Univ. of Wis.
8020 Young, C. L., Univ. of Wash.
8021 Tucker, B. H., Jr., Univ. of Texas.
8022 Holben, W. P., Pa. State Coll.
8023 Newmeyer, W. L., Jr., Case School of Applied Science
8024 Kramer, A. W., Amour Inst. Tech.
8025 Giles, W. M., Mass. Inst. Tech.
8026 James, A. P., Armour Inst. Tech.
8027 Brand, C.M., Carnegie Inst. Tech.
8028 Tribbett, C. A., Yale Univ.
8029 Garmany, G. M., Univ. of Va.
8030 Woodruff, E. C., Univ. of Calif.
8031 Kouyoumjian, G., Univ. of Ill.
8032 Berdan, C. H., N. Y. Elec. Sch.
8033 Lux, G. J., Mich. Agri. College.
8034 da Costa, M. F., Univ. of Ill.
8035 Yamamoto, S. T., Univ. of Ill.
8036 Scutari, C., N. Y. Elec. Sch.
8037 Haveson, H., N. Y. Elec. Sch.
8038 Mills, R. H., Mass. Inst. Tech.
8039 Mellen, E. R., Mass. Inst. Tech.
8040 Hassinger, M. A., Pa. State Coll.
8041 Olson, W. J., Univ. of Wash.
8042 Tanzer, W. M., Seattle Engg. Sch.
8043 Broome, F. H., Rutgers College
8044 Mooney, R., Univ. of Illinois
8045 Smith, E. R., Lafayette College.
8046 Williams, R. V., Colorado College.
8047 Hoard, G. T., Univ. of Wash.
8048 Rowley, M. K., Univ. of Penna.
8049 Sheahan, E. H., Syracuse Univ.
8050 Norton, L. D., Univ. of Nebraska.
8051 Mateer, H. W., Univ. of Illinois.
8052 Norman, M. J., Bucknell Univ.
8053 Hackett, H. N., Ore. Agri. Coll.
8054 Russell, E. G., Lewis Institute.
8055 Vandenberg, G. J., Univ. of Wash.
8056 Schlough, F. H., Lafayette Coll.
8057 Schach, J. F., Armour Inst. Tech.
8058 Koenig, K., Armour Inst. Tech.
8059 Dunne, J. P., Armour Inst. Tech.
8060 Dyck, A. R., Armour Inst. Tech.
8061 Jarvis, R., Univ. of Illinois.
8062 Melby, E. C., Univ. of Minn.
8063 Bleecker, G. W., Univ. of Minn.
8064 Anderson, F. L., Univ. of Minn.
8065 Croswell, D. R., Univ. of Minn.
8066 Teberg, E. J., Univ. of Minn.
8067 Abbott, A. H., Univ. of Minn.
8068 Simons, W. W., Univ. of Minn.
8069 Dow, W. J., Univ. of Minn.
8070 Goree, A. W., Ga. Sch. Tech.
8071 Tisinger, T. F., Ga. Sch. Tech.
8072 Stanley, E. A., Ga. Sch. Tech.
8073 Newton, B. D., Mass. Inst. Tech.
8074 Price, G. F., Brooklyn Poly. Inst.
8075 Nash, F. H., Kans. St. Agri. Coll.
8076 Johnson, J. V., Univ. of Calif.

8077 Fore, F. K., N. Y. Elec. School.
8078 Whiteside, J. H., Mont. State Coll.
8079 Hands, H. A., Mass. Inst. Tech.
8080 Slater, B. F., Lewis Institute.
8081 Meyer C., Carnegie Inst. Tech.
8082 Hunter, S., Univ. of Wash.
8083 Braff, J. P., N. Y. Elec. School.
8084 Hough, C. C., Cornell Univ.
8085 O'Brien, D. H., Cornell Univ.
8086 Smith, W. R., Cornell Univ.
8087 Aznar, L. F., Univ. of Penna.
8088 Fowler, W. K., Jr., Univ. of Neb.
8089 Sarvas, O., Cooper Union.
8090 Motz, A. S., Univ. of Wash.
8091 Van Duyne, C. W., Stevens Inst. Technology.
8092 Morgan, A. L., Stanford Univ.
8093 Stuart, A. B., Stanford Univ.
8094 Lindsay, H. W., Univ. of Illinois.
8095 Yamada, F. T., Univ. of Wash.
8096 Helmer, W. S., Univ. of Michigan.
8097 Woodbury, T.C., Wentworth Inst.
8098 Gallaher, H. T., Univ. of Illinois.
8099 Humphrey, K. B., Univ. of Ill.
8100 Junken, L. H., Purdue University.
8101 Bush, G. P., Univ. of Illinois.
8102 Ward, A., Yale University.
8103 Scott, L. E., Yale University.
8104 Silliman, F., 3rd, Yale University.
8105 Melrose, C. J., Wash. State Coll.
8106 Halteman, J. F., Penna. State Col.
8107 Allgeier, O. R., Univ. of Missouri.
8108 Johnson, E. T., Penna. State Coll.
8109 Olson, V. O., N. Y. Elec. School.
8110 Collier, D. C., Bliss Elec. School.
8111 Hodgson, J. A., McGill Univ.
8112 Casey, J. C., Highland Park Coll.
8113 Wells, E. M., Armour Inst. Tech.
8114 Brady, R. A., Iowa State College.
8115 Ribble, C. H., Lafayette College.
8116 Norris, F. W., Univ. of Nebraska.
8117 Greenspahn, S., Univ. of Mich.
8118 Yorkey, W. R., Cornell Univ.
8119 Weightman, J. W., Los Angeles Poly. Junior College.
8120 Nulsen, W. B., Los Angeles Poly. Junior College.
8121 Schonborn, R. J., Los Angeles Poly. High School.
8122 Summers, I. H., Los Angeles Poly. Junior College.
8123 Pendleton, D. C., Los Angeles Poly. Junior College.
8124 Evans, P. G., Los Angeles Poly. Junior College.
8125 Leuteritz, H. C., Stuyvesant Evening Trade School.
8126 Prince, L. H., Los Angeles Poly. High School.
8127 Espe, O., Los Angeles Polytechnic Junior College.
8128 Wilson, G. F., Los Angeles Poly. High School.
8129 Cordes, H. A., Los Angeles Poly. Junior College.
8130 Leech, V. E., Los Angeles Poly. Junior College.
8131 Shroyer, D. E., Tri-State College of Engineering.
8132 Delsasso, L. P., Los Angeles Poly. Junior College.
8133 Rugg, H. H., South Dakota School of Mines.
8134 Meyer, G. C., Finlay Engineering College.
8135 Boye, G. E. W., Stuyvesant Evening Trade School.

Total 125.

ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

American Electric Railway Association. Proceedings 1915. 5 vols. (Accountants Association, American Association, Claims Association, Engineering Association, Transportation and Traffic Association.) New York, 1915. (Exchange.)

——Year Book 1915-16. New York, 1916. Exchange.

American Telephone & Telegraph Company. Annual Report of the Directors to the stockholders. Dec. 31, 1915. New York, 1916. (Gift of Company.)

UNITED ENGINEERING SOCIETY

American Electric Railway Association. Studies in the cost of urban transportation service, by F. W. Doolittle. New York, 1916. (Purchase.)

Central Station Management. By H. C. Cushing, Jr. & Newton Harrison. New York, 1916. (Purchase.)

Clauses and Precedents in Electricity, Gas and Water Legislation. Compiled by Jacques Abady. London, 1915. (Purchase.)

Directions for Designing, making and operating high pressure transformers. By F. E. Austin. Montpelier, Vt., 1914. (Purchase.)

II. Eigenschaften und Eignung der verschiedenen-Systeme elektrischer Traktion. B. Allgemeiner Vergleich der Eigenschaften und Eignungder verschiedenen Systeme. Zurich 1915. (Purchase.)

Electric Railway Engineering. By C. F. Harding & D. D. Ewing. Ed. 2 New York, 1916. (Purchase.)

Electrical Ignition of Petrol Engines. By J. W. Warr. London, 1910. (Purchase.)

Electrical Measurements and Meter Testing. By D. P. Moreton, Chicago, 1915. (Purchase.)

Elementary Manual of Radiotelegraphy and Radiotelephony for students and operators. By J. A. Fleming. Ed. 3. New York, 1916. (Purchase.)

Essentials of Electrical Engineering. By John F. Wilson. New York, 1915. (Purchase.)

Hawkins' Electrical Dictionary. New York, n. d. (Purchase.)

International Engineering Congress. Panama Canal, vols. 1-2. Municipal Engineering, vol. 3. San Francisco, 1915. (Purchase.)

Irrigation Practice and Engineering. Vol III—Irrigation structures and distribution system. New York, 1916. (Purchase.)

Military Electric Lighting. Vol. I-II. London, 1909, 1915. (Purchase.)

Overhead Transmission Lines and Distributing Circuits, their design and construction. By K. Kapper, translated by P. R. Friedlaender. New York, 1915. (Purchase.)

Theory and Calculation of electric currents. By J. L. LaCour and O. S. Bragstad. New York, 1913. (Purchase.)

GIFT OF CONNELL & CONNELL

A good collection of Engineering News, Engineering Record, Engineering-Contracting, Electrical World and Street Railway Journal. All unbound.

GIFT OF F. J. LISMAN & COMPANY

American Institute of Mining Engineers. Transactions, vols. 29-31, 1899-1901.

Manual of American Water Works. 1897.

U. S. Bureau of Statistics, Foreign Commerce and Navigation of the U. S. 1888, 1889, 1890, 1892.

EMPLOYMENT DEPARTMENT

Note: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-123. Opening for operating man, familiar with general power house practise; maintenance of generators, engines, wiring, etc. Salary about $2000. Please state age, qualifications, etc.

V-124. Manufacturing company located in middle west requires the services of an advertising manager, with technical training. Give particulars as to age, experience, salary desired and other details.

V-125. Superintendent, for factory engaged in manufacture of oil and gasoline engines. Must be familiar with modern methods of manufacture, active, tactful, a close student of human nature and a natural leader. Exceptional manufacturing men, even though not actively engaged in gas engine work, are encouraged to reply. Position offers a splendid opportunity for one who can qualify. Give complete experience.

MEN AVAILABLE

470. Technical graduate desires position in New York State or New England. One year in apprenticeship course of the Westinghouse E. & M. Co. Experience in industrial motor application. Age 25; now employed. Would prefer industrial application or power sales, but will consider any line of engineering work.

471. Electrical Engineer, college graduate. Westinghouse apprentice one and a half years. Government consulting and illuminating engineer two years. Some knowledge of Spanish. Open for employment October 1, 1916.

472. Electrical Engineer would like to get in touch with general manager of an electric utility in a large or moderate size city. At present employed but wishes to enter a larger field. Has had wide experience in the generation, distribution and utilization of electric power, and in administrative and commercial work.

473. Electrical Engineer, age 29, married. Technical graduate and graduate of training course for instructors in vocational schools. Eight years' all-around experience in central station operation. Two years' experience as electrician in large industrial plant. Willing to associate with others in proposition, receive living expenses and invest balance of salary in proposition.

474. Engineering or industrial publicity position desired by a graduate mechanical (electrical) engineer, with six years' experience in engineering, business, and publicity work. Can handle advertising, sales correspondence collection and arrangement of technical and business data, or manage house organ. Prefer metropolitan district. Initial salary $2,000, with prospects.

475. Teaching position wanted by student member, Cornell 1916, M. E., with six years' good experience with prominent manufacturers of motors, generators and transformers. Also interested in other work along line of previous experience.

476. An experienced electrical engineer, now teaching in a large university, is available for summer work on valuation, design or any special problems. Have had four years' banking experience as well as good technical training.

477. Electrical Engineer, with excellent technical training, desires position, preferably with consulting engineer or operating company, but will consider anything. Degree from Cornell University. Four years' operating and construction work. Have been teaching engineering several years but wish to re-enter active practise. Age 36; married; excellent health. Available June 1.

478. Electrical Engineer, technical graduate, age 29, married. Five years' experience, installation, operation and maintenance of signal systems on steam railroads. Thoroughly familiar with all types of signal installations. Capable of estimating material and labor costs, and handling men. One year's experience in valuation work. Minimum salary $1800.

479. Electrical Engineer, technical graduate, two years' testing experience and six years sales and office experience in vicinity of New York City, desires position as sales engineer or New York representative. Well acquainted among central stations, operating companies and isolated plants.

480. Constructing Engineer, large experience in electrical, mechanical, and structural work, desires change which will enable him to spend more of his time at home.

481. Electrical Engineer, age 30, married. Nine years' experience; desires position in or near New York City in construction, operation, selling or experimenting in fields of railway, wireless, automobile or specialty. Minimum salary $1800.

482. Electrician, experienced in power plant operation and all branches of inside construction. Fifteen years' experience. Seven years chief electrician a-c. isolated plant Worcester Polytechnic Institute. Eight years in contracting line; heavy mill construction. At present superintendent and estimator large contracting concern. Age 34; married; education, electrical engineer, correspondence instruction.

483. Electrical Engineer, technical graduate, age 27. Two years G. E. apprentice, two years with public utilities company. Desires position as superintendent of either or both testing and meter departments with public utilities company, or investigation work with public utilities company or consulting engineering company.

484. Engineer-Executive, twenty years in electric light and power field, would correspond with firm or corporation requiring whole or part time services of expert. Experience includes design, construction and management of hydroelectric and steam power systems, appraisals, reports, financing, rate and contract making, etc.

485. Efficiency-Employment Engineer. Young man, graduate electrical and mechanical engineer, experienced in efficiency work, particularly as to costs and labor problems, desires to become connected with some organization in this capacity. Employment department or sociological work preferred, but is also versed in the accounting and engineering end of efficiency work.

486. Electrical Engineer, university graduate, age 28, desires to become associated with engineering contractor as business partner. Experienced in electrical and other engineering con-

struction costs. Willing to invest and spend whole time on the development of the business. Philadelphia vicinity preferred, but will consider other locations.

487. Technical Graduate, six years' experience, clear record, thoroughly familiar with motor application and control, generators and turbines. Prefer position as mill engineer, with either a consulting engineering or manufacturing company. Three years' experience with large manufacturer of electrical apparatus.

488. Electrical Engineer; age 30; married. Ten years' experience; six years hydroelectric operation and installation; four years substation construction. At present in charge of large hydroelectric plant. Desires change. Moderate salary to start; will go anywhere.

489. Electrical Engineer-Superintendent, technical graduate; age 36; married. Fifteen years' experience in engineering, construction and operation of railway, lighting and power stations and transmission systems with General Electric, Westinghouse, large construction and public utilities companies. Familiar with specifications, contracts, reports, estimates, etc. Available May 1.

490. Electrical Engineer, 1909 graduate. One year as instructor in electrical engineering in large university; five years' experience in design, construction, operation and valuation of electric railways and nine months with consulting engineer, reporting upon electric railway feeder systems. Desires position in the East which offers opportunity to grow.

491. Electrical Engineer, technical graduate; age 28; single. Two years' experience manufacturer's test and transformer engineering department. One year in engineering department large utility company. Desires position with opportunity for advancement.

492. Assistant Electrical Engineer, Columbia graduate, age 31; single; of good habits; desires position in New York City. One year in railway and substation work, several years in building maintenance and automobile repairs. Also business experience as manager of garage. Had highest percentage in New York State examination for assistant electrical engineer.

493. Electrical Engineer, technical and college graduate, 29 years of age, four years' experience, desires a position as engineering salesman or purchasing agent with a progressive concern. Experienced in the rubber industry, and in electrical inventory and appraisal work.

494. Electrical Engineer, 30, wishes responsible position on Pacific Coast. Five years' design and construction 100,000-h.p. 60,000-volt hydroelectric power system, and superintendent meter and connection department. Also experience in electric traction, operating and maintenance, telephone, time systems, and electrolysis investigation. Thoroughly competent; up-to-date; hustler.

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Revised to May 1, 1916

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Revised to May 1, 1916

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Term expires July 31, 1918.
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Term expires July 31, 1919.
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Term expires July 31, 1920.
Carl Hering, Harris J. Ryan,
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Term expires July 31, 1917.
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Revised to May 1, 1916.

Name and when Organized		Chairman	Secretary
Atlanta	Jan. 19, '04	A. M. Schoen	H.E. Bussey, 3d Nat. Bk. Bldg. Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead	L. M. Potts Industrial Bldg, Baltimore, Md.
Boston	Feb. 13, '03	L. L. Elden	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago	1893	W. J. Norton	Taliaferro Milton, 613 Marquette Building, Chicago, Ill.
Cleveland	Sept. 27, '07	E. H. Martindale	Irving H. Van Horn, National Lamp Works, Nela Park, Cleveland, Ohio.
Denver	May 18, '15	W. A. Carter	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor	Jan. 13, '11	Ralph Collamore	C. E. Wise, 427 Ford Bldg., Detroit, Mich.
Fort Wayne	Aug. 14, '08	J. J. Kline	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Ind.
Indianapolis-Lafayette	Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Kansas City, Mo.	Apr. 14, '16	Gordon Weaver	Glenn O. Brown, Kansas City Elec. Lt. Co., Kansas City, Mo.
Los Angeles	May 19, '08	E. Woodbury	R. H. Manahan, 32 City Hall, Los Angeles, Cal.
Lynn	Aug. 22, '11	G. N. Chamberlin	F. S. Hall, Gen.Elec.Co., West Lynn, Mass.
Madison	Jan. 8, '09	M. C. Beebe	F. A. Kartak, Univ. of Wis., Madison, Wis
Mexico	Dec. 13, '07		
Milwaukee	Feb. 11, '10	R. B. Williamson	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota	Apr. 7, '02	E. T. Street	Walter C. Beckjord, St. Paul Gas Light Co., St. Paul, Minn.
Panama	Oct. 10, '13	William H. Rose	C. W. Markham, Balboa Heights, C. Z.
Philadelphia	Feb. 18, '03	J. H. Tracy	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh	Oct. 13, '02	T. H. Schoepf	G. C. Hecker, 436 Sixth Avenue, Pittsburgh, Pa.
Pittsfield	Mar. 25, '04	M. O. Troy	F. R. Finch, General Electric Company, Pittsfield, Mass.
Portland, Ore.	May 18, '09	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Rochester	Oct. 9, '14	E. L. Wilder	F. E. Haskell, 93 Monica Street Rochester New York.
St. Louis	Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco	Dec. 23, '04	A. H. Babcock	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady	Jan. 26, '03	L. T. Robinson	F. W. Peek, Jr., Gen. Elec. Co., Schenectady, N. Y.
Seattle	Jan. 19, '04	C. E. Magnusson	C. F. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Spokane	Feb. 14, '13	Victor H. Greisser	C. A. Lund, Washington Water Power Co., Spokane, Washington.
Toledo	June 3, '07	W. E. Richards	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto	Sept. 30, '03	D. H. McDougall	
Urbana	Nov. 25, '02	P. S. Biegler	T. D. Yensen, Univ. of Illinois, Urbana, Ill.
Vancouver	Aug. 22, '11	R. F. Hayward	H. N. Keifer, Northern Electric Company, Ltd., Vancouver, B. C.
Washington, D. C.	Apr. 9, '03	R. H. Dalgleish	Arthur Dunlop, National Electric Supply Company, Washington, D. C.

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LIST OF BRANCHES

Name and when Organized		Chairman	Secretary
Agricultural and Mech. College of Texas	Nov. 12, '09	A. Dickie	G. B. Hanson.
Alabama, Univ. of	Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of	Mar. 25, '04	P. X. Rice	F. M. Ellington, University of Arkansas, Fayetteville, Ark.
Armour Institute	Feb. 26, '04	A. A. Oswald	J. F. Hillock, Armour Institute of Technology, Chicago, Ill.
Brooklyn Poly. Inst.	Jan. 14, '16	Albert H. Bernhard	Walter J. Seeley, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University	May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of	Feb. 9, '12	J. V. Kimber	H. A. Mulvaney, 1521 Hopkins Street, Berkeley, Cal.
Carnegie Inst. of Tech.	May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of	Apr. 10, '08	W. A. Steward	R. H. Kruse, 75th and Main Streets, Cincinnati, Ohio.
Clarkson Col. of Tech.	Dec. 10, '15	W. A. Dart	C. J. Dresser, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col.	Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College	Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of......Dec. 16, '04	E. F. Peterson	Samuel J. Blythe, University of Colorado, Boulder, Colo.
Georgia School of Technology..............June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College..Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.........June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College.....Apr. 15, '03	F. H. Hollister	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of..........May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agric. Col., Manhattan, Kansas.
Kansas, Univ. of........Mar. 18, '08	E. C. Arnold	E. C. Burke, 1214 Kentucky Street, Lawrence, Kansas.
Kentucky, State Univ. of Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College.......Apr. 5, '12	Rodman Fox	Frank H. Schlough, Lafayette College, Easton, Pa.
Lehigh University.......Oct. 15, '02	A. F. Hess	R. W. Wiseman, Lehigh University, South Bethlehem, Pa.
Lewis Institute..........Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of.........Dec. 26, '06	A. A. Packard	E. V. Crimmin, Univ. of Maine, Orono, Me.
Michigan, Univ. of......Mar. 25, '04	U. M. Smith	N. F. Brown, University, of Michigan Ann Arbor, Mich.
Missouri, Univ. of.......Jan. 10, '03	K. Atkinson	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col.......May 21, '07	Taylor Lescher	J. A. Thaler Montana State College, Bozeman, Mont.
Nebraska, Univ. of......Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts......Feb. 11, '10	R. V. Davis	R. L. Kelly, West Raleigh N. C.
North Carolina, Univ. of.Oct 9 '14	Edw. Y. Keesler	W. H. Joyner, Univ. of North Carolina. Chapel Hill, N. C.
Ohio Northern Univ......Feb. 9, '12	H. H. Robinson	F. W. Evans, 302 E. Lincoln Avenue, Ada, Ohio.
Ohio State Univ.........Dec. 20, '02	R. G. Locket	D. A. Dickey, Ohio State University, Columbus, Ohio.
Oklahoma, Agricultural and Mech. Col...........Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of......Oct. 11, '12	Clifford O. Oster	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon Agr. Col.........Mar. 24, '08	Winfield Eckley	J. A. Hooper, Oregon Agric. College, Corvallis, Ore.
Penn. State College......Dec. 20, '02	C. L. Knotts	William W. Herold, Jr., State College, Pa.
ittsburgh , Univ. of....Feb. 26, '14	G. R. Patterson	W. K. Benz, University of Pittsburgh, Pittsburgh, Pa.
Purdue University.......Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Rensselaer Poly. Inst....Nov. 12, '09	W. J. Williams	S. N. Galvin, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst...Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col. Mar. 14, '13	C. E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ...........Dec. 13, '07	A. B. Stuart	H. J. Rathbun, Stanford University, Cal.
Syracuse Univ...........Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.........Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin, Tex.
Throop College of Technology...............Oct. 14, '10	J. W. DuMond	K.W. Rich, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute.................Jan. 8, '15	V. Dixon	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of.......Feb. 9, '12	W. S. Rodman	J.H. Moore, Dawsons Row, University, Va.
Wash. State Col. of.....Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Coll. of Wash. Pullman, Wash.
Washington Univ.......Feb. 6, '04	P. C. Roberts	Charles A. Lieber, Washington University, St. Louis, Mo.
Washington Univ. of....Dec. 13, '12	E. C. Miller	Geo. S. Smith, Univ. of Washington, Seattle, Wash.
West Virginia Univ......Nov. 13, '14	H. C. Schramm	C. L. Walker, West Virginia Univ., Morgantown, W. Va.
Worcester Poly, Inst.....Mar. 25, '04	R. M. Thackeray	C. C. Whipple, Worcester Polytechnic Institute, Worcester, Mass.
Yale University.........Oct. 13, '11	P.G. von der Smith	S. R. Large, 343 Elm Street, New Haven, Conn.

Total 54.

American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXV **JUNE, 1916** **Number 6**

A. I. E. E. ANNUAL CONVENTION

The Thirty-Third Annual Convention of the American Institute of Electrical Engineers will be held at the Hollenden Hotel, Cleveland, Ohio, June 27 to 30, 1916. The Convention Committee and its various sub-committees have been actively engaged in formulating plans for the coming convention, which are now completed.

There will be five technical sessions, as scheduled below, and numerous entertainment features which will make the convention both profitable and enjoyable to all who attend.

PROGRAM

Reprints of all papers will be available without charge at registration headquarters.

Tuesday, June 27

9:00 A.M.

Registration

10:00 A. M.

Address of Welcome by Mayor Harry L. Davis.

President's Address, by John J. Carty.

Industrial Power Session

Electric Drive for Reversing Rolling Mills, by Wilfred Sykes and David Hall.

Motor Equipment for the Recovery of Petroleum, by W. G. Taylor.

12:30 P. M.

Sections Committee luncheon.
Ladies' luncheon.

2:30 P. M.

Transmission Session.

Report of Transmission Committee, by Percy H. Thomas, Chairman.

Effect of Barometric Pressure on Temperature Rise of Self-Cooled Stationary Apparatus, by V. M. Montsinger.

Restoring Service after a Necessary Interruption, by F. E. Ricketts.

7:30 P. M.

Dinner-dance and reception.

Introduction of President-Elect H. W. Buck.

Wednesday, June 28

10:00 A. M.

Protective Apparatus Session.

Studies in Lightning Protection on 4000-Volt Circuits, by D. W. Roper,

Experience in Recent Developments of Central Station Protective Features. by N. L. Pollard and J. T. Lawson.

Protection of High-Tension Distribution Systems by Isolating Transformers, by O. O. Rider.

Megger and Other Tests on Suspension Insulators, by F. L. Hunt.

Experiences in Testing Porcelain Insulators, by E. E. F. Creighton.

New Method of Grading Suspension Insulators, by R. H. Marvin.

12:30 P. M.

Sections Committee luncheon.

2:30 P. M.

Automobile trip.

6:30 P. M.

Board of Directors' meeting and dinner.

8:30 P. M.

Sections Committee Conference, open to all members.

8:00 P. M.

Theatre party for ladies.

Thursday, June 29

10:00 A. M.

Electrophysics Session.

Effect of High Continuous Voltage on Air, Oil and Solid Insulation, by F. W. Peek, Jr.

The Corona Voltmeter, by J. B. Whitehead and M. W. Pullen.

Theory of Parallel Grounded Wires and Production of High Frequency in Transmission Lines, by E. E. F. Creighton.

2:00 P. M.

Games and other entertainment at Nela Park.

6:00 P. M.

Dinner at Nela Park.

7:15 P. M.

Special cars from Nela Park to Shaker Heights Country Club.

8:30 P. M.

Meeting at Shaker Heights Country Club.

Presentation of Past-President's Badge, followed by dancing.

Friday, June 30

All-day boat trip.

9:30 A. M.

City of Erie leaves dock at foot of East 9th Street.

10:00 A. M.

Technical Session.

Suggestions for Electrical Research in Engineering Colleges, by V. Karapetoff.

Tractive Resistances to a Motor Delivery Wagon on Different Roads and at Different Speeds, by A. E. Kennelly and O. R. Schurig.

Application of a Polar Form of Complex Quantities to the Calculation of A-C. Phenomena, by N. S. Diamant.

12:30 P. M.

Luncheon on board *City of Erie*.

5:45 P. M.

Boat arrives at Cleveland.

Conference of Branch Delegates.

A conference of delegates from the Student Branches of the Institute has been authorized by the Board of Directors and will be held at some convenient time during the convention. Past-President Charles F. Scott will preside at this conference.

ENTERTAINMENT

The Convention Committee and its various sub-committees have provided a program of entertainment features of more than usual scope and interest. Full details of all entertainment features will be printed in the pamphlet program which will be distributed at convention headquarters.

Hotel Rates

The headquarters of the Institute during the Convention will be in the Hotel Hollenden.

The rates at the Hollenden and other available hotels, all of which are on the European plan, are as follows:

Hotel	Room without bath		Room with bath	
	One Person	Two Persons	One Person	Two Persons
Hollenden, Superior & E. 6th Sts. (Headquarters)	$1.50	$3.00	$2.00 to 5.00	$3.00 to 6.00
Colonial, Colonial Arcade	2.00 to 3.00	3.50	2.50 to 3.00	4.00 to 4.50
Olmstead, Superior & E 9th Sts.			1.50 to 3.00	3.00 to 5.00
Statler,* Euclid & E. 12th St.	1.50 to 2.00	3.00 to 4.00	2.50 to 3.50	4.00 to 10.00

*Rooms listed as without bath have shower bath only.

Transportation

No special transportation rates are available, and members should consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

PACIFIC COAST CONVENTION, SEATTLE, SEPTEMBER 5-8, 1916

As announced in previous issues, the Pacific Coast Convention of the Institute will be held this year in Seattle, Wash., September 5-8, under the auspices of the Seattle Section. Committees are actively formulating plans for the meeting, and the technical program and other details will be announced in future issues of the PROCEEDINGS.

CONSTITUTIONAL AMENDMENTS

As stated in the report of the Annual Meeting of the Institute held May 16, 1916, all of the constitutional amendments recently submitted to the membership have been adopted, and in accordance with the constitution will become effective June 15, 1916.

Pamphlet copies of the constitution, as amended, will be available, without charge, after June 15, upon application to the Secretary.

PAN-AMERICAN ENGINEERING COMMITTEE

At the meeting of the Board of Directors of the Institute held January 14, 1916, the following resolutions were adopted:

"WHEREAS, there is a general movement throughout the Americas for a closer political, social, scientific, commercial and industrial association among its numerous states, and for the reason that engineering is such an important factor in such development, it is

"RESOLVED, that in order that the National Engineering Societies of America may bear their part in this desirable movement and at the same time increase and broaden their influence and usefulness throughout the Americas, the American Institute of Electrical Engineers invite the American Society of Civil Engineers, the American Institute of Mining Engineers, and the American Society of Mechanical Engineers to join with it in forming a joint committee to be known as the Pan-American Engineering Committee, to be composed of a total of twenty members, five members from each society, which committee be requested to outline whatever procedure for future action is deemed desirable in the premises, and to report back to the respective governing bodies represented thereon."

Each of the societies mentioned appointed five representatives upon this joint committee and the committee has organized by the election of Mr. William McClellan as chairman, and Mr. F. Lavis, 50 Church Street, New York, as secretary.

The committee desires to obtain a list of the members of the four national societies who have had actual experience in South and Central American countries together with the names of the countries with which each member is familiar. The purpose of this is to acquire information and data which may be of use to the committee in attempting to formulate its plan, or in an endeavor to obtain the cooperation of all who may be interested.

Members of the Institute who are interested are therefore requested to communicate with the secretary of the joint committee, whose name and address are given above.

I. E. S. LECTURES ON ILLUMINATING ENGINEERING AT UNIVERSITY OF PENNSYLVANIA

In 1910 a course of lectures on illuminating engineering was given at Baltimore under the joint auspices of the Illuminating Engineering Society and John Hopkins University which

marked an important step in the development of illuminating engineering, and the reprinted lectures have been in demand ever since. These lectures were so successful that it has been decided to give a new course of about twenty lectures by recognized authorities, under the joint auspices of the Illuminating Engineering Society and the University of Pennsylvania, September 21-28, 1916, following the society's annual convention, in Philadelphia.

Whereas the 1910 course dealt chiefly with illumination as a science, the new course will emphasize the art of illumination and the various aspects of lighting practise. In connection with the lecture there will be an exhibition, also at the University of Pennsylvania, of the latest developments in illuminating appliances, including lamps, accessories, photometers, etc., together with novel applications of light. There will also be organized an inspection tour including visits to manufacturing establishments, laboratories, lighting companies and notable lighting installations.

The price of tickets for the lecture course has been fixed at $25, which includes admission to all lectures and functions associated with the lecture course, reprint of the lectures, and in addition, reprint of the 1910 lectures. The chairman of the administrative committee having in charge the arrangements for the course is Mr. Preston S. Miller, 80th Street and East End Avenue, New York, N. Y.

DELEGATE FROM ENGINEERING STANDARDS COMMITTEE OF GREAT BRITAIN

Mr. C. le Maistre, of London, arrived in New York on May 12, having been appointed official delegate of the Engineering Standards Committee of Great Britain, to attend meetings of the Standards Committee of the American Institute of Electrical Engineers held May 15-16.

Mr. le Maistre, who is also General Secretary of the International Electrotechnical Commission, with headquarters in London, attended preliminary conferences on May 12 and 13 with a sub-committee of the Standards Committee, attended the meetings of the Standards Committee on May 15-16, as well as a joint meeting of the Standards Committee and the U. S. National Committee of the I. E. C. on May 16.

Mr. le Maistre also attended the New York session of the National Meeting of the Institute on the evening of May 16 and took part in the programme by extending greetings from his committee to the 5000 members of the A. I. E. E. assembled in the six cities where simultaneous sessions were held.

During the latter part of May and the early part of June he will make a short tour of the United States and Canada, visiting places of engineering interest, and will return to New York about June 10 for further conferences relative to standardization.

A. I. E. E. ANNUAL MEETING, NEW YORK, MAY 16, 1916

The Annual Meeting of the Institute was held at Institute headquarters, 33 West 39th Street, New York, on Tuesday, May 16, 1916, at 4:30 p. m. President John J. Carty called the meeting to order, and called upon Secretary Hutchinson to present the Annual Report of the Board of Directors for the fiscal year ending April 30, 1916. Copies of the report, which is printed in Section II in this issue of the PROCEEDINGS, were available at the meeting.

The report of the Committee of Tellers upon its canvass of the ballots cast for the election of officers was presented. The president thereupon announced the election of the following officers for the administration year beginning August 1, 1916: President, H. W. Buck, New York; Vice-Presidents, L. T. Robinson, Schenectady, N. Y., Peter Junkersfeld, Chicago, Ill., B. A.

Behrend, Boston, Mass.; Managers, John B. Fisken, Spokane, Wash., Charles Robbins, Pittsburgh, Pa., N. A. Carle, Newark, N. J., Charles S. Ruffner St. Louis, Mo.; Treasurer, George A. Hamilton, Elizabeth, N. J.

The report of the Committee of Tellers of its canvass of the votes cast upon the amendments to the constitution was then presented. The report showed that a total of 2951 votes had been cast, of which number 226 were rejected for various constitutional reasons. The total vote cast was 33.2 per cent of the total membership, and the votes in favor of adoption of the various groups of amendments ranged from 95.5 to 99 per cent. As the total vote cast exceeded 30 per cent of the total membership, and as the vote in favor of adoption exceeded 75 per cent of the total vote cast upon each amendment, the President declared the amendments adopted. Both reports of the Committee of Tellers are published elsewhere in this issue of the PROCEEDINGS.

On motion the meeting then took a recess, to convene again at 8:30 p.m., in the auditorium of the Engineering Societies Building, as a part of the National Meeting conducted simultaneously in six cities by means of the long-distance telephone, as referred to elsewhere in this issue.

A. I. E. E. NATIONAL MEETING MAY 16, 1916

The National Meeting of the American Institute of Electrical Engineers held simultaneously by means of long-distance telephone in Boston, New York, Philadelphia, Atlanta, Chicago and San Francisco, was called to order by President J. J. Carty, at 8.30 o'clock, Tuesday evening, May 16.

This unique meeting was planned to commemorate the achievements of members of the Institute in the fields of communication, transportation, light and power. The auditoriums in the six cities in which the meeting was held were connected by telephone and every person in attendance was provided with an individual telephone receiver. Each of the participating gatherings took an active part in the conduct of the meeting and all of the speakers scattered over the country from San Francisco to Boston were distinctly heard by every one in attendance at the six cities.

President Carty in New York presided over the entire meeting. The chairmen of the Sections presided in the other cities—at San Francisco, Mr. A. H. Babcock; at Chicago, Mr. W. J. Norton; at Atlanta, Mr. A. M. Schoen; at Philadelphia, Mr. J. H. Tracy; and at Boston Prof. Charles R. Cross presided at the invitation of Chairman L. L. Elden. President Carty in calling the meeting to order stated that it was an adjourned session of the Annual Meeting which had been held early in the afternoon. He then called upon Secretary Hutchinson to call the roll of the cities in which the meeting was held. Atlanta reported 500 present, San Francisco 750, Boston, 900 Philadelphia 850, Chicago 1000, and New York 1100.

President Carty then sent greetings to all the members of the A. I. E. E. assembled in the different parts of the United States and said: "I think we are all to be congratulated on the flourishing condition of the Institute, and on the manifold achievements of its membership, not only in the department of communication, but in the development of electric lighting, electric power and electric transportation. I am particularly pleased to report that the members throughout the country are responding most patriotically to the call of President Wilson which was issued some time ago asking them to take part in the new industrial mobilization which is now taking place. At this time I think it is proper for me to read a message which has just been received from Woodrow Wilson, President of the United States:"

White House, Washington
9:58 a.m., May 16, 1916.

John J. Carty, President.
American Institute of Electrical Engineers,
33 West 39th Street, New York.

May I not extend my warm congratulations to you and to the members of the American Institute of Electrical Engineers, upon the unique and singularly interesting meeting into which it has gathered its members in Boston, San Francisco, Atlanta, Chicago, Philadelphia and New York. To conduct such a meeting by telephone and make it possible for men scattered all over the country to listen to the proceedings and participate in them, is certainly a most interesting evidence of the inventive genius and engineering ability represented by the Institute. It is with genuine satisfaction that I avail myself of this occasion to express my own deep appreciation of the work of the Institute in the development of the country's resources.

WOODROW WILSON

The next in the order of business was the presentation of the report of the Committee of Tellers on the election of officers for the ensuing year, which report is printed elsewhere in this issue of the PROCEEDINGS. President Carty then introduced President-elect H. W. Buck, who made a few brief remarks of acknowledgment, stating that he accepted the honor which had been given him with a feeling of solemnity and a full sense of the responsibility inposed by the office, and he bespoke the cooperation of the various committeemen and Board of Directors for the incoming administration.

Dr. Alexander Graham Bell, past-president of the Institute, was next introduced and responded with a few words of greeting, saying that he was proud to have been a president of this Institute and was glad to be alive, as it was not many men who lived to see the fruition of their thoughts as they go beyond them, for the telephone had gone far beyond him; and he hoped to live some time longer to see what others would do to improve telephonic communication, although he did not see how it could be much improved.

Mr. Carty next introduced Mr. Theodore N. Vail, who has been a member of the Institute from the beginning, and who was not only a leader in telephone work but was a pioneer in storage batteries and electric traction, water power development and high-tension transmission. Mr. Vail congratulated the members of the Institute upon its growth and accomplishments in the electrical field, which work and accomplishments were largely if not entirely due to those who were represented at this meeting, among them many who only 32 years ago in the struggling uncertain days organized the Institute. Many of them are still with us but to all of them the world owes a debt of gratitude and appreciation.

President Carty next introduced Mr. C. le Maistre, representing all of the British engineering societies, who came from London to New York as the special delegate of the Engineering Standards Committee of Great Britain. to attend the meeting of the A. I. E. E. Standards Committee. Mr. le Maistre offered most cordial greetings on behalf of the International Electrotechnical Commission and the Engineering Standards Committee of Great Britain.

Mr. Thomas A. Watson, the early associate of Dr. Bell in the development of the telephone, was then introduced by President Carty as "the man who first heard words spoken over the telephone and who ran the first telephone line, and is indeed the first telephone engineer." Mr. Watson sent his greetings to the electrical engineers scattered all over the United States and congratulated them on the wonderful things which had happened during past years in the development of the telephone.

At 9 o'clock after the conclusion of Mr. Watson's remarks the telephonic proceedings were suspended for a half-hour to provide for the delivery of local addresses in the six cities. These addresses were delivered to audiences of the different Sections by noted educators, as follows: Boston, Dr. A.

Lawrence Lowell, president of Harvard University; New York, Dr. John H. Finley, president of the University of the State of New York; Philadelphia, Dr. Edgar H. Smith, provost of the University of Pennsylvania; Atlanta, Dean C. E. Ferris of the engineering faculty of the University of Tennessee; Chicago, Dr. Harry Pratt Judson, president of the University of Chicago; and San Francisco, Dr. Ray Lyman Wilbur, president of Leland Stanford, Jr., University. The keynote of all the local addresses was the work and accomplishments of the engineers.

Dr. A. Lawrence Lowell reviewing the progress of man in civilization showed the relation of that growth step by step to man's control of nature's forces. The discovery of electricity and the development of electrical engineering marked the greatest single advance. Electrical energy can be transmitted over great distances distributed and transmuted into almost every known form of energy and with little loss. All this has had, is having and will continue to have, effects upon the social relations of man. Greater agents may be discovered but whatever the character of future discoveries the fact remains that any profound invention or discovery in the control of natural forces must have an effect no less profound on the structures of social life.

Steam, machinery, electricity have helped to discredit the idea that any class in a community exists to promote the welfare of another class. On the other hand they have given rise to industry on a large scale and with it the factory problem with its subordination of the individual to system. This problem would have caused much less trouble to mankind if it had been foreseen. The more the work of a profession affects social conditions the greater the duty to use imagination in foreseeing the effects of an advance. This is a heavy and perplexing responsibility and upon no profession does it rest today more surely than upon that of engineering and especially upon the A. I. E. E.

Dr. Finley eulogizing the work of S. F. B. Morse and Joseph Henry exhibited the apparatus used by Henry in the experiments which constituted the first electromagnetic telegraph. He called attention to the fact that man's history has been a struggle from a lower to a higher state of mobility. We have acquired the art of locomotion, but far more important than mobility of the body is mobility of the mind and more important than all is transmobility of ideas.

Mobility must be destinated and given a purpose, and the Institute is doing an important part through the achievements of its members in making it possible that this great Republic of ours should exist permanently, holding its parts together. This higher mobility should lead to an expression of American spirit, by which every man may hear the call from this great center, from the American nation, calling him to his particular duty in the democracy.

Provost Edgar H. Smith made a strong plea for the incorporation of a broader training in chemistry in the preparation of Electrical Engineers, contending that if they were made more intimately acquainted with the chemical constitution of the bodies about us, that the great conquests which have been theirs would be excelled and surpassed by others.

He dwelt on the present commercial situation in America, cut off from certain foreign supplies—the intensity of interest in the development of our natural resources, and the possibilities of securing abundant supplies of potash and other needed materials by electrical means.

He advocated liberal governmental support for the carrying out of research problems in engineering.

He closed by lauding the achievements of Bell, Edison, Thomson, Marconi and others saying, "to you, and to those upon whom your mantles

fall—the real miracle-workers of the world—I humbly bow, offering my heartfelt gratitude and sincerest thanks—and ask—what next?"

Dean C. E. Ferris spoke of the changes that had been wrought in the material fabric of our civilization by the work of the engineer, culminating in the achievements of the electrical engineer. In the development of the telephone, particularly, so well illustrated by the National Meeting, we have an agency which is doing wonders in making rural life more attractive by doing away with the old-time isolation, a result which is very important for the future of our country. Electrical engineers have been devoting their time and genius to making more light, driving back crime and ignorance, lengthening the productive hours of each day, making beauty where once was ugliness. The electrical engineer has done no greater service than to make possible the long-distance distribution of power—a service not so much to this as to future generations, as the utilization of our water power will help to leave to future generations the decision as to whether they wish to exhaust the earth's supply of stored heat energy in coal and oil and gas. The engineer has done his wonderful work under remarkably favorable conditions—he has had the cooperation of the physicist, chemist, the mechanical and mining engineer, and the man of pure science. It is this spirit of cooperation that has made modern engineering achievements possible.

President Harry Pratt Judson said that the progress of civilization consists largely in man's mastery over natural forces, and in recent years that mastery has taken the form, to a great extent, of the transformation of these forces into electricity, and in this way of the transmission of force to great distances and to countless applications. The power of civilization today to a very large extent consists in the application of our knowledge of electricity, and these applications are largely attributable to the two or three decades just passed. The members of the Institute in a single generation have seen accomplished and have enormously aided in accomplishing, some of the greatest achievements which the world has seen, and if the work of the Institute's members should by some strange happening be obliterated, it would really set the world back, not thirty years, but a century. It is a privilege to be connected with a profession like this. Looking into the future, we cannot tell what new forms of electrical engineering will appear, but we may be sure that this body of trained men will advance as rapidly tomorrow as yesterday.

President Wilbur emphasizing the great service rendered by engineers and the persistent progress of the science and art of electricity called to mind the advances this progress had made possible. Its relationship to communication, transportation, light, power, its influence on city life, on the types of buildings we work in, on agriculture, irrigation, on the life of each one of us, be he farmer, miner, physician, scholar or business man.

Growth comes only from unrest, from struggle, from attempts at assimilation. It is the spirit of dissatisfaction with present attainment that we want to make part of every fibre of our educational institutions. To accept the present would be fatal to the University as it would have been to this Institute had it decided to stop its work ten years ago. America has developed such rare men as Edison and Bell but perhaps there are others who will unveil for the service of the world new and unthought of vistas of electrical force. It is the new that lures us on. The triumph of the future can only be built upon the success of the search made for it now.

The Universities ask the Institute for help and encouragement in their endeavors to inculcate the proper ground work in those who come to them and also in carrying on lines of research that may seem impractical and unpro-

ductive. Such work must be done, if any science is to advance. Working together the Universities and the members of this Institute should see a wonderful result upon every inhabitant of this great planet in years to come.

At the conclusion of Dr. Finley's address in New York, President Carty stated that after the meeting had been planned there were many urgent requests to connect up other Sections, but the danger of interruption was so great that it was found necessary to hold the program down to the original dimensions. It was found possible, however, in the case of Denver, which is the youngest Section of the Institute, to arrange for the entire Section to listen to the proceedings, but it was not practicable for them to take part in the meeting. He then read a telegram from the Denver Section as follows: "Mr. J. J. Carty; Denver Section with 50 present sends greetings to you and the Institute and President-elect Buck. We have heard everything clearly. W. A. Carter."

It was also arranged for a number of Institute members to listen to the meeting at Salt Lake City, from which President Carty received the following telegram: "President J. J. Carty; Forty-five local members of the Institute assembled here send enthusiastic greetings on the wonderful success of the demonstration. Meeting greatly appreciated. A. S. Peters."

Telephone proceedings were then resumed and greetings were received from the different Sections. President Carty called on Atlanta to send its greetings to all of the other members who were listening. Chairman Schoen responded as follows:

"Atlanta, located in the Piedmont section of the southern Appalachians, among their racing rivers and roaring falls, whose energy has been dragged forth and laid at her doors through high-tension transmission and in whose phenomenal development no factor has been more potent than the electrical engineer, sends greetings."

Boston was next called upon, and Prof. Cross responded as follows:

"Boston sends warmest greetings to her sister cities. The telephone was born here and here it first spoke, but 'its sound has gone out into all lands and its words unto the ends of the world'."

Mr. Peter Junkersfeld responded from Chicago, saying—

"Chicago sends greetings from the Great Lakes to the Atlantic and Pacific. Next week we will welcome cordially many members of the Institute who are central station engineers, and two weeks later those who are merely politicians—in any event we will be glad to see you all on these as well as other occasions and we promise you a very hearty welcome."

President Carty sent greetings on behalf of New York as follows:

"I wish to say that the members assembled here send their greetings to all of their fellow members everywhere throughout the United States, and the New York members feel this means a permanent union of all the Sections of the Institute into one harmonious Institute, without any sectional feeling, and that this meeting emphasizes the fact that sectionalism in the Institute, as well as in the country at large, is a thing of the past, and that with the instruments which have been developed by the members of the Institute, sectionalism in our country is forever dead."

Mr. John A. Britton responded for San Francisco as follows:

"San Francisco hails its fellow members of the Institute. Our potentials have created your possibilities and our necessities provoked your initiative, an initiative undisturbed by referendum or recall. California has by the pioneer spirit of domination created needs which the world has followed—the snow-crowned Sierras opened up the path of gold to the path of energy, which tonight makes it possible for us on the western rim of the continent of peace to be in instant touch with men who have harnessed rivers, bridled precipices, drawn from the ether that silent and unseen energy that has leveled distance and created force to move the world along lines of greater civilization by closer contacts. Hail to the engineers, harbingers of peace and usefulness."

Chairman J. H. Tracy of Philadelphia sent greetings as follows:

"Philadelphia sends most cordial greetings to the members of the Institute throughout the United States. We

congratulate the Institute, the company by whose courtesy this meeting is held, and President Carty who has rendered such distinguished service to both. We congratulate them and this meeting on the wonderful development and the result which it has made possible, and at this time when so much thought is being devoted to national preparedness we congratulate them on the fact that in the handling and transmission of intelligence this country has been for years prepared far in advance of any other country in the world. Dr. Smith has spoken to us this evening about the telephone in the development of our national resources, and has made a plea for a broader view in the preparation of our electrical engineers, that the great achievements which we have already had may be excelled by succeeding development and be of greater economic value. We are glad to take part in this National Meeting. We are proud of the accomplishments of our fellow members. We are proud of our fellow members."

President Carty then announced that after having exchanged greetings with all of the Sections the next thing in order would be some music, whereupon various national airs played on phonographs were transmitted over the wires from the different cities as follows—Atlanta, "Dixie Melodies"; Boston, "Yankee Doodle"; Chicago, "America" New York, "Hail Columbia"; San Francisco, "Columbia the Gem of the Ocean"; Philadelphia, "Star Spangled Banner."

At the conclusions of the musical selections President Carty called on Dr. Michael I. Pupin, who delivered an address on "The Engineering Profession." Dr. Pupin paid an eloquent tribute to the engineering profession, stating that the magnificent accomplishments of engineers had placed them in the front ranks of great public benefactors.

The final speaker of the evening was Honorary Secretary Ralph W. Pope, who congratulated the Institute on the fact that its Annual Meeting had been extended in its scope so as to include the whole United States, but hoped that in the future our 32 or even more Sections might all take part in our Annual meetings. At the conclusion of Mr. Pope's remarks Prof. Harris J. Ryan in San Francisco offered the following resolution:

Resolved, that this National Meeting of the American Institute of Electrical Engineers in Boston, San Francisco, Atlanta, Chicago, Philadelphia and New York now assembled, does hereby express its deep appreciation of the efforts of all those who have cooperated in the holding of such a meeting, which is now for the first time held in any country; and that a record of the proceedings of this meeting which is made possible by the inventive genius and by the engineering ability of its own membership, be spread upon the minutes of the Institute, where, for generations to come, it will serve as an inspiration to engineers everywhere, and will mark an epoch in the history of American engineering achievement.

The President: "You have all heard the resolution. Is the resolution seconded?"

Prof. Charles R. Cross (Boston): "I second the resolution."

The President: "The resolution is duly made and seconded. Is there any discussion?"

Mr. J. H. Tracy (Philadelphia): "I move an amendment to the effect that the secretary of the Institute be instructed to send to each of the speakers of the evening a copy of this resolution."

Mr. Bancroft Gherardi (New York): "I second that amendment."

The President: "The amendment is seconded."

Mr. A. H. Babcock: "Professor Ryan of San Francisco accepts the amendment."

The President: Is the amendment accepted in Boston?"

Prof. Charles R. Cross: "The amendment is accepted in Boston."

The President: "Are you ready for the question on the resolution as amended? If you are, all in favor say 'aye'; contrary minded 'no'. The resolution is carried."

"If there is no further business to come before the meeting, a motion to adjourn would be in order."

A. M. SCHOEN (Atlanta): "I move that the meeting adjourn."

W. J. NORTON (Chicago): "I second the motion."

THE PRESIDENT: "The motion is duly made and seconded that the meeting do now stand adjourned. All in favor please say 'aye'; contrary minded 'no'. The motion is carried, and the meeting stands adjourned."

CRITICALLY DAMPED GALVANOMETERS

The Bureau of Standards, Washington, D. C., has recently issued scientific paper No. 273, entitled "General Design of Critically Damped Galvanometers."

This investigation was begun some years ago because the best galvanometer then obtainable was not sufficiently sensitive for some of the Bureau's work, and has been continued because of the increasing need for very sensitive galvanometers.

The paper gives the relation between the operation constants, or those constants with which the user is concerned, and the construction constants which depend upon the size, shape, etc., of the parts, and with which the maker is concerned. In particular it shows what values the construction constants must be made to have in order that a galvanometer may meet definite performance specifications. Sensitive moving-coil galvanometers are primarily considered, but much of the discussion applies also to less sensitive galvanometers with pointers, and to the moving-coil permanent-magnet type of instruments. Free copies may be obtained by those interested by addressing a request to the Bureau of Standards.

MEMBERSHIP COMMITTEE

The following figures show the number of applications for admission to the Institute received from the beginning of the fiscal year, June 1, 1915, to May 31, 1916, inclusive:

Sections	Applications Received June 1, 1915 to May 31, 1916.	Per Cent of Present Section Membership
Atlanta	7	16.
Baltimore	9	10.
Boston	17	4.7
Chicago	37	10.
Cleveland	32	18.6
Denver	28	56.
Detroit-Ann Arbor	12	9.
Fort Wayne	5	11.6
Indianapolis-Lafayette	4	8.
Ithaca	5	8.
Los Angeles	9	6.
Lynn	7	8.
Madison	3	8.8
Milwaukee	9	7.
Minnesota	4	5.
Panama	8	12.7
Philadelphia	20	6.
Pittsburgh	53	13.
Pittsfield	7	4.9
Portland	2	2.
Rochester	6	10.
St. Louis	19	15.
San Francisco	24	8.5
Schenectady	40	11.
Seattle	10	12.6
Spokane	1	1.8
Toledo	3	11.5
Toronto	11	7.5
Urbana	7	25.9
Vancouver	2	3.
Washington, D. C.	11	12
	412	

Total number of members located in section territory		4272	
Percentage for Section territory			9.5%
Received from applicants outside Section territory	405		
Total number members outside Section territory		3954	
Percentage for outside territory			10.%
Totals	817	8226	

REPORT OF COMMITTEE OF TELLERS ON ELECTION OF OFFICERS

To the President,
American Institute of Electrical Engineers.

DEAR SIR:—This committee has carefully canvassed the ballots cast for officers for the year 1916-1917. The result is as follows:

Total number of ballot envelopes received..		2581
Rejected on account of bearing no identifying name on outer envelope, according to Art. VI, Sec. 33 of the Constitution	22	
Rejected on account of voter being in arrears for dues on May 1, 1916, as provided in the Constitution and by-laws	39	
Rejected on account of ballot not being enclosed in inner envelope, or on account of inner envelope bearing an identifying name, according to Art. VI, Sec. 33 of the Constitution	47	
Rejected on account of having reached the Secretary's office after May 1, according to Art. VI, Sec. 33 of the Constitution	23	131
Leaving as valid ballots		2450

These 2450 valid ballots were counted and the result is shown as follows:

For President

H. W. Buck	2449
Scattering and blank	1

For Vice-Presidents

L. T. Robinson	2249
Peter Junkersfeld	2219
B. A. Behrend	2049
Henry A. Lardner	789
Scattering and blank	44

For Managers

John B. Fisken	2375
Charles Robbins	2351
N. A. Carle	2212
Charles S. Ruffner	2177
Scattering and blank	685

For Treasurer

George A. Hamilton	2450
Scattering and blank	

Respectfully submitted,

FREDERICK BORCH, *Chairman*
WILLIAM A. MOORE,
R. H. CARPENTER,
RICHARD MAETZEL,

May 10, 1916. *Committee of Tellers.*

REPORT OF COMMITTEE OF TELLERS ON AMENDMENTS TO THE CONSTITUTION

To the Board of Directors,
American Institute of Electrical Engineers.

GENTLEMEN:—This committee has canvassed the ballots cast on the amendments to the Constitution submitted to the membership in a circular letter dated March 15, 1916, and the result is as follows:

Total number of envelopes received....	2951
Of these the following were rejected in accordance with the Constitution and by-laws for the reasons given below:	
No identifying name on envelope	140
In arrears for dues on May 1, 1916	56
Received after May 9, 1916	10
Blank ballots	20
Total invalid ballots	226
Leaving as valid ballots	2725

These valid ballots were counted and the result is as follows.

ALL OF THE AMENDMENTS ARE COMPRISED IN THE FOLLOWING GROUPS

Against Adoption		For Adoption	Per cent of Total Vote
20	Group A—Miscellaneous matters	2705	99
25	Group B—Election and transfer of members	2700	99
73	Group C—Life membership	2652	97
46	Group D—Delinquent members	2679	98
65	Group E—Remission of dues	2660	97.5
55	Group F—Terms of office	2670	98
37	Group G—Vacancies in office	2688	98.5
39	Group H—Election of officers	2686	98.5
50	Group J—Board of Directors	2675	98
20	Group K—Finance	2705	99
21	Group L—Administration	2704	99
33	Group M—Committees	2692	98.5
36	Group N—Meetings	2689	98.5
93	Group O—Annual Meeting quorum	2632	96.5
127	Group P—Amendments	2598	95.5
24	Group Q—Numbering sections of constitution	2701	99

The total vote cast was 33.2 per cent of the total membership. To be adopted 75 per cent of the vote cast must be in favor of adoption. The percentages in favor of the respective groups are indicated in the right-hand column.

Respectfully submitted,

FREDERICK BORCH, *Chairman*
R. H. CARPENTER,
RICHARD MAETZEL,
WM. A. MOORE,

May 12, 1916. *Committee of Tellers.*

DIRECTORS' MEETING, NEW YORK, MAY 16, 1916

The regular monthly meeting of the Board of Directors of the Institute was held at Institute headquarters in New York on Tuesday, May 16, 1916, at 2:30 p.m.

There were present: President J. J. Carty, New York; Past-Presidents C. O. Mailloux, New York, P. M. Lincoln, Pittsburgh, Pa.; vice-Presidents, N. W. Storer, Pittsburgh, Pa., Farley Osgood, Newark, N. J. C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William McClellan, New York; Managers H. A. Lardner, New York, L. T. Robinson, Schenectady, N. Y., Frederick Bedell, Ithaca, N. Y., Bancroft Gherardi, New York, A. S. McAllister, New York, C. E. Skinner, Pittsburgh, Pa., John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa., Treasurer, George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $8,647.27 was ratified.

The report of the Board of Examiners of its meeting held on May 10 was read and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners 51 students were ordered enrolled, 83 applicants were elected as Associates, one applicant was reinstated as an Associate, nine applicants were elected as Members, one applicant was transferred to the grade of Fellow, and two applicants were transferred to the grade of Member, in accordance with the lists printed elsewhere in this issue of the PROCEEDINGS.

Upon the petition of Professor George D. Shepardson, and with the approval of the chairman of the Sections Committee, authority was granted to organize a Branch at the University of Minnesota.

Mr. F. L. Hutchinson was unanimously appointed secretary of the Institute for the administrative year beginning August 1, 1916.

The Annual Report of the Board of Directors for the fiscal year ending April 30, 1916, which had been prepared by the secretary, containing a summary of the work of the Institute during the year, together with a general balance sheet showing the condition of the Institute's finances, was approved for submission to the membership at the Annual Meeting later in the afternoon.

The annual report of the treasurer was received and accepted, also the reports of Institute committees, which the secretary was directed to file for reference by incoming committees of the succeeding administration.

Announcement was made of the death of William Stanley on May 14, and resolutions were unanimously adopted by a rising vote in tribute to Mr. Stanley's memory.

A considerable amount of other business was considered, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

PAST SECTION MEETINGS

Atlanta.—May 2, 3 and 4, 1916, Georgian Terrace Hotel. Conference on proposed National Safety Code, ninety-two representatives attending, with Dr. E. B. Rosa of the Bureau of Standards presiding.

Baltimore.—April 14, 1916, Engineering Building, Johns Hopkins University. Paper: "Industrial Leadership," by H. L. Gantt. The Section was the guest of the Department of Engineering of Johns Hopkins University. Attendance 72.

Chicago.—April 24, 1916. Subject: The Central Station in Cities of Less than 50,000 Inhabitants. Papers: (1) "Thoughts in Connection with the Electrical System of Small Central Stations," by Albert J. Goedjen; (2) "Station Management," by Adam Gschwindt; (3) "The Distribution of

Electrical Energy, with Particular Reference to Small Communities," by A. Hardgrave; (4) "The City Manager," by R. L. Fitzgerald. Joint meeting with Western Society of Engineers. Attendance 90.

Cleveland.—April 17, 1916, Chamber of Commerce. Paper: "A Modern D-C. Substation," by G. B. Schneeberger. Paper illustrated with lantern slides. Attendance 36.

Denver.—April 15, 1916, Denver Athletic Club. Paper: "Steam Railroad Electrification," by W. H. Edmunds. Joint meeting with Denver Section of American Society of Civil Engineers. Attendance 75.

Detroit-Ann Arbor.—April 14, 1916, Detroit. Paper: "Electrical Equipment for Automobiles," by Frank Conrad. Attendance 40.

Fort Wayne.—May 18th, 1916, Commercial Club. Address by Mr. W. S. Goll on "The Owen Magnetic Car." Attendance 47.

Indianapolis-Lafayette.—April 21, 1916, Indianapolis. Illustrated lecture on "The Mississippi River Power Plant at Keokuk," by C. A. Sears. Attendance 124.

Kansas City.—April 25, 1916, Y. M. C. A. Building. Election of officers as follows—chairman, Gordon Weaver; secretary-treasurer, Glenn O. Brown. Attendance 15.

Los Angeles.—April 25, 1916, Chamber of Commerce. Paper: "The Electric Range, Its Manufacture, Load Possibilities, and Advantage to the User," by A. W. Childs. Attendance 69.

Milwaukee.—May 10, 1916, Republican House. Illustrated lecture by Dr. H. E. Horton on "Through the Furnace to the Farm." Meeting under auspices of American Chemical Society. Attendance 70.

Panama.—April 30, 1916, Balboa Heights. Lecture by Major McK. Saltzman on "The Work of the Signal Corps, U. S. Army." Attendance 27.

Philadelphia.—February 14, 1916, Engineers Club. Paper: "Electrical Progress in the Textile Industry," by John S. Henderson, Jr. Attendance 80.

March 17, 1916, Engineers Club. Paper: "Engineering Training as a Business Asset," by Charles F. Scott. Joint Meeting with Philadelphia Section of Illuminating Engineering Society. Attendance 100.

March 23, 1916, Engineers Club. Paper: "Recent Developments in Electrical Apparatus," by Harold Pender. Joint meeting with Franklin Institute. Attendance 250.

April 10, 1916, Engineers Club. Subject: The Possibilities of Some Prime Movers now under Development. Papers: (1) "The Uniflow Engine," by A. D. Skinner; (2) "Future Possibilities of the Large Steam Turbine Generator in Electric Generating Service," by W. C. L. Eglin: (3) "The Diesel Engine," by W. B. Piersol. Joint meeting with Philadelphia Branch of American Society of Mechanical Engineers. Attendance 300.

Pittsburgh.—May 9, 1916. Lecture by Mr. B. G. Lamme on "Technical Training for Engineers." Attendance 115.

Portland.—March 30, 1916, Oregon Building. Bi-weekly luncheon of A. I. E. E. and N. E. L. A. Sections, followed by address by Mr. C. C. Chapman on "Civic Problems." Attendance 41.

Rochester.—April 28, 1916, Rooms of Rochester Engineering Society. Paper: "Pioneer Electrical Engineering," by J. H. Vail. Attendance 33.

San Francisco.—May 2, 1916, Native Sons Hall. Meeting on "Military Preparedness." Joint meeting of the local sections of the Civil, Mechanical, Mining, Chemical and Electrical Engineers. Attendance 300.

Schenectady.—May 4, 1916, Union College Gymnasium. Lecture by Mr. Walter D'Arcy Ryan on "Illumination of the Panama-Pacific International Exposition." Lecture was illustrated by over 200 colored lantern slides. Attendance 1,250.

Spokane.—April 21, 1916, Washington Water Power Building. Paper:

"Transformer Connections, Installation and Operation," by V. H. Greisser and M. W. Birkett. Mr. J. C. Ralston gave a short talk on "Industrial Preparedness." Attendance 52.

St. Louis.—May 10, 1916, Engineers, Club. Paper: "Protection of Buildings against Lightning," by Terrell Croft. Attendance 50.

Toledo.—May 10, 1916, Toledo Commerce Club. Illustrated lecture by Mr. A. Seeger on "The Curtis Steam Turbine." Moving pictures entitled "Some European Engineering Views." and ' The Use of Lifting Magnets in the Steel Industry." Attendance 30.

Toronto.—May 5, 1916, Engineers Club. Election of officers as follows—chairman, E. T. Brandon; vice-chairman, E. M. Ashworth; secretary, Wills Maclachlan· executive committee, T. M. De Blois, W. G. Gordon and A. H. Hull. Attendance 13.

PAST BRANCH MEETINGS

University of Arkansas.—May 2, 1916 Paper: "Resources of Arkansas" by W. N. Gladson. Election of officers as follows: chairman, A. L. Wilson; secretary-treasurer, W. L. Teague. Attendance 15.

May 17, 1916. Paper; "Triple Brake Valves' by J. C. Moody. Paper: illustrated by lantern slides. Attendance 12.

Brooklyn Polytechnic Institute.—April 13, 1916, Mailloux Library. Experimental lecture by Dr. Erich Hausman on "Polarized Light." Paper; "Behavior of Carbon Brushes under Excessive Currents" by J. Van R. Wall. Attendance 38.

Bucknell University.—May 1, 1916, Electrical Laboratory. Address by Mr. John Banks on "The Storage Battery." Attendance 18.

University of California.—April 12, 1916. Paper: "Electric Separation of Water from Crude Oil" by Mr. Holzer. Attendance 18.

University of Cincinnati.—March 9, 1916, Engineering Building. Address by Dr. McGhee on "Relation of Economics to Engineering." The address was followed by an entertainment. Joint meeting with local branch of A. S. M. E. Attendance 127.

April 11, 1916, Engineering Building. Paper: "Some Problems of the Consulting Engineer" by Walter Franz. Attendance 33.

Clarkson College of Technology.—April 27, 1916. Addresses by Professors Towle and Powers on "Engineering Experiences." Attendance 9.

May 10, 1916, Papers: (1)"Installation, Testing and Records of the Service Meter" by P. R. Pierson; (2) "Test of Electric Railway Cars and Locomotives' by F. F. Van Voorhis. Attendance 13.

Colorado State Agricultural College. May 2, 1916, Electrical Building. Moving pictures on "The Induction Motor and Direct Drive." Attendance 20.

Georgia School of Technology.—April 24, 1916, Kuhns Cafe. Banquet of Branch and electrical seniors. Addresses by Professors Wood, Freeman and Schroeder. Attendance 25.

Iowa State College.—April 12, 1916. Address by Dr. O. H. Cessna on "The Applications of Psychology to Business." Attendance 13.

University of Kansas.—May 10, 1916, Marvin Hall. Nomination of officers for the coming year as follows: chairman, N. M. Foster; vice-chairman, E. C. Burke; secretary-treasurer, G. M. Bowman. Attendance 33.

Lafayette College.—March 27, 1916, Pardee Hall. Papers: (1) "The Automatic Substation" by L. R. Fox; (2) "Street Lighting Systems" by A. S. Turner. Attendance 22.

April 3, 1916, Pardee Hall. Papers: (1) "Prime Movers for Central Stations' by C. E. Woodring; (2) "Gas-Electric Cars" by H. A. MacFadden. Attendance 21.

April 10,1916, Pardee Hall. Papers: (1) "Automobile Starting and Lighting Equipment" by S. B. Hunt; (2) "Motor Requirements in the Portland Cement Industry" by F. H. Schlough. Attendance 21.

April 17, 1916, Pardee Hall. Papers: (1) "Portable Substations" by R. S. Kramer; (2) "The Trackless Train" by H. Mumma. Attendance 24.

May 1, 1916, Pardee Hall. Papers: (1) "Electric Heating" by H. A. Bailey; (2) "Train Lighting" by S. M. Wikel. Attendance 9.

May 8, 1916, Pardee Hall. Papers: (1) "Flood Lighting for Public Buildings" by R. L. Dunlap; (2) "Electric Signs, Types and Uses" by P. H. Taylor. Attendance 12.

University of Michigan.—April 28, 1916, New Engineering Building. Paper: "Transformers" by E. H. Bailey. Attendance 79.

University of Nebraska.—March 1, 1916, Electrical Engineering Building. Addresses on "The Block Signal System" by Messrs. Ackerman, G. E. Hancock and P. McCoullough. Attendance 15.

April 5, 1916, Mechanical Engineering Building. Illustrated lecture by Prof. C. L. Dean on "Refrigeration as a Source of Revenue for Central Stations." Attendance 20.

April 27, 1916, Brace Hall. Addresses by Prof. W. S. Franklin on "Some Mechanical Analogies in Electricity and Magnetism." Attendance 25.

Ohio Northern University.—April, 19 1916, Dukes Memorial. Paper: "Military Field Telegraph" by Mr. Blackford. Address by Mr. Wickerham on "Block Signals." Attendance 23.

May 2, 1916, Dukes Memorial. Address by Prof. Sleesman on "Organic Chemistry," followed by general business meeting. Attendance 27.

Oregon Agricultural College.—April 14, 1916. Address by Mr. Paul Lebenbaum on "Electrifying Railroads and Some of its Problems." Attendance 25.

May 4, 1916. Messrs. Peaslee and Oakes gave a high tension display in the high tension laboratory. Attendance 23.

Pennsylvania State College.—April 5, 1916, Engineering Club Room. Paper: "Electrification of the Pennsylvania Railroad." Attendance 45.

May 3, 1916, Engineering Club Room. Address by Prof. J. O. Kammerman on "Corporation Development Along Industrial Lines". Attendance 40.

University of Pittsburgh.—March 22, 1916, Thaw Hall. Paper: "Diesel Internal Combustion Engines as Prime Movers" by G. M. Kratzert. Attendance 15.

April 5, 1916, Thaw Hall. Paper: "The Control and Protection of Electric Systems" by R. T. Johnson. Attendance 18.

Syracuse University.—April 27, 1916. Papers: (1) "Power Supply Stations in Central New York"; (2) "Chicago, Milwaukee and St. Paul Railway Electrification." Attendance 13.

May 4, 1916. Paper: "The Development of Artificial Lighting" by G. A. Laurer. Attendance 13.

University of Texas.—March 17, 1916 Papers: (1) "The Development of the Incandescent Lamp" by Mr. Howe; (9) "Proposed Rearrangement of the Street Lighting System of a Texas City of about 50,000 Inhabitants" by F. B. Johnson. Attendance 35.

April 7, 1916, Papers: (1) "Lighting and Power Load Curves of the University of Texas Campus" by W. A. Darter; (2) "Cost of Installing and Operating a Power Station for the University of Texas" by F. N. Zant. Attendance 17.

May 5, 1916. Subject: Industrial Power. Illustrated lecture on "Electricity on the Farm". Paper: "Choice of Motors for Various Classes of Service" by J. I. Blucher. Attendance 10.

Washington State College.—April 28, 1916, Mechanics Arts Building. Address by Prof. Thompson on "The Use of Electricity in the Mining Industry." Attendance 11.

University of Washington.—April 13, 1916, Armory Building. Moving picture films of the application of electricity.

May 2, 1916, Forestry Building. Illustrated address by Mr. J. D. Ross on "The City Light Plant of Seattle and the Need for More Power." Attendance 39.

Worcester Polytechnic Institute.—April 21, 1916, Lecture Hall. Address by Mr. F. M. Feiker on "The Electrical Engineer and His Industry." Attendance 34.

Yale University.—May 19, 1916, Electrical Laboratory. Paper; "Electrification of Steam Railroads" by E. R. Hill. Paper illustrated by lantern slides. Election of officers for the coming year as follows: chairman, A. W. Cahoon; secretary, J. P. Allen; treasurer, E. F. Thrall. Attendance 120.

PERSONAL

MR. J. ROBERTS WILSON, formerly sales manager and vice-president of the Crocker-Wheeler Company of Ampere, N. J., has become associated with the Davison Chemical Corporation of Baltimore, Md., as manager of the companys office at 120 Broadway, New York.

MR. ROBERT A. CARLTON, for many years inspector of construction with the Edison Electric Illuminating Company of Boston, and Mr. ALBERT E. MACE, have resigned their positions with that company, and have organized a construction company, the Carleton-Mace Engineering Corporation, to specialize in central station and industrial power plant installation and electric transmission systems. The offices are at 38 Chardon Street, Boston, Mass.

MR. L. HERBERT KELLER, who for the last three years has been manager of the Chicago district office of the Moloney Electric Company, has moved to St. Louis, Mo., having been advanced to an executive position in the general offices of the company. Mr. Ralph B. Coleman has succeeded Mr. Keller as manager of the Chicago office.

OBITUARY

ENOS M. BARTON, chairman of the board of directors of the Western Electric Company, died on May 3, 1916, at his southern home in Biloxi, Miss., at the age of seventy-two years. He was born in Jefferson County, New York, and began work at the age of twelve as a messenger in the telegraph office at Watertown, N. Y. He became an operator, and worked in New York during the Civil War, sending night press reports. Then he went to Rochester as chief operator of the Western Union office in that city. In 1869 the Western Union shop at Cleveland, Ohio, was to be abandoned, and George W. Shawk, who had been foreman of the shop, bought part of the equipment and engaged in miscellaneous work, including the making of inventors' models. Mr. Barton went into partnership with him. This firm became successively Gray and Barton, the Western Electric Manufacturing Company, and the Western Electric Company. Mr. Barton was successively secretary, vice-president and president of the Western Electric Company, and since his retirement from the presidency in 1908 he had been chairman of its board of directors. He was elected an Associate of the Institute July 12, 1887.

HENRY FLOY, Fel. A. I. E. E., consulting electrical engineer and valuation expert, died suddenly at his residence in New York City on May 5, 1916, in his forty-ninth year. He was born in Elizabeth, N. J., and after being graduated from Wesleyan University with the degrees of A.B. and A.M., he studied engineering at Cornell University and received the degree of M.E. in 1891. From 1892 to 1898 Mr. Floy served with the Westinghouse company in its shop, engineering and sales departments. In 1898 he resigned as manager of the Minneapolis office of that company to be associated in New York with Professor R. C. Carpenter of Cornell as a consulting engineer. Mr. Floy in-

stalled the first 25,000-volt underground transmission line, in 1900, at St. Paul, Minn. Since 1901 he had been in business for himself. He acted as arbitrator in the Colorado Springs, Col., lighting controversy, and served in many important appraisal cases in New York City, Buffalo, Springfield, Mo., and other places. He has been a frequent contributor to the technical press, and is the author of a number of volumes, including "High Tension Underground Electric Cables," "Valuation of Public Utility Properties," and a book which has just recently appeared, "Value for Rate-Making." Mr. Floy was elected an Associate of the Institute May 17, 1892, transferred to the grade of Member January 10, 1908, and transferred to the grade of Fellow June 27, 1912. At the time of his death he was a member of the Institute's Board of Examiners.

WILLIAM STANLEY, Fel. A. I. E. E., one of the pioneer electrical engineers and inventor of many of the fundamental devices that have made possible the great development of the electrical industry, died in Great Barrington, Mass., May 14, 1916, after a long illness. William Stanley was born November 22, 1858, in Brooklyn, N. Y. He prepared for college at Williston Seminary, and entered Yale with the class of 1881, but left college in his freshman year because he wanted to take up the study of electricity by himself. He engaged in nickel-plating in New York, and then engaged in work for the United States Electric Light Company, in New York. Later, while connected with the Swan Electric Light Company of Boston, Mr. Stanley invented and perfected an improved method of exhausting incandescent lamp bulbs. In 1883 he established a private laboratory in Englewood, N. J., where he carried on experimental work on storage batteries and other apparatus. In the following year he undertook for the late George Westinghouse certain investigations which were to be taken up as business enterprises if successful. In 1885, while in Pittsburgh, Mr. Stanley devised the "multiple" system of alternating-current distribution, designing transformers and generators, and developing the system, but Mr. Westinghouse was unwilling to invest any money in this development work. Mr. Stanley therefore carried it on at his own expense, hiring an abandoned rubber factory in Great Barrington, Mass., and building twelve transformers and other apparatus. In the spring of 1886 he installed his alternating-current system of distribution, supplied by a Siemens alternator borrowed from Mr. Westinghouse, and transformers and lamps were placed in several of the Great Barrington stores and a regular commercial service successfully begun. In April, 1886, Mr. Westinghouse visited Great Barrington with some of his friends and inspected the Stanley plant, and this led to the development of the Westinghouse Electric Company and its construction of a second plant at Buffalo, N. Y., in the fall of the same year. Mr. Stanley designed a new type of alternator for his system. From 1888 to 1890 he continued as general consulting engineer for the Westinghouse interests, but severed the connection in 1890 to establish the Stanley Laboratory in Pittsfield, Mass., in association with Mr. Cummings C. Chesney and Mr. John F. Kelly. Together they worked out the famous "S. K. C. system" of long-distance transmission of alternating-current from an inductor type generator. In 1894 the first power transmission was put into operation by this system, a water power at Algeria, formerly the Stockbridge Iron Works, supplying energy for a system which transmitted electrical power to mills at Housatonic and Great Barrington. The Stanley Electric Manufacturing Company, which manufactured this equipment, later became the Pittsfield works of the General Electric Company. Mr. Stanley made many other inventions, including condensers, two-phase motors, generators, and an alternating-current meter employing magnetic suspension

of its moving parts. Of recent years Mr. Stanley had been engaged in consulting work with the General Electric Company, developing an electric range designed to operate at unity load factor. In 1913 he was awarded the Edison Medal, being the fourth to receive this honor. He was elected an Associate of the Institute December 6, 1887, transferred to the grade of Member October 26, 1898, and the grade of Fellow May 20, 1913. He served as a vice-president of the Institute for the term 1898-1900.

The funeral was held at Great Barrington on May 16, and a committee of members of the Institute was appointed to attend. The following resolutions were adopted by the Board of Directors at its meeting on May 16:

WHEREAS, by the death of William Stanley on May 14, 1916, there passed away one of the leading pioneers in the electrical field, whose genius in the early days of electrical development gave him a foremost place in industrial history, and

WHEREAS, his meritorious work in the invention and development of the transformer, and of alternating-current systems and apparatus, for which he was awarded the Edison Medal, the highest honor in this country for electrical achievements, marks him as one of the greatest of electrical inventors, and

WHEREAS, his long connection with this Institute, since 1887, when he became an Associate, his services as a Vice-President from 1898 to 1900, and his continued friendly interest in its welfare, earned for him the gratitude and esteem of its officers and members, be it

RESOLVED, that the Board of Directors of the American Institute of Electrical Engineers hereby expresses its profound sorrow at the death of one of its most distinguished members and its sense of the irreparable loss to the engineering profession; and it extends to the members of the family of Mr. Stanley its deep sympathy in their bereavement. Be it further

RESOLVED, that these resolutions be inscribed in full in the minutes, and that a copy thereof be transmitted to the members of Mr. Stanley's family.

RECOMMENDED FOR TRANSFER, MAY 10, 1916

The Board of Examiners, at its regular monthly meeting on May 10, 1916, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

TO THE GRADE OF MEMBER

CHELLIS, GEORGE FREDERICK, Electrical Engineer, J. G. White Engineering Corp., San Francisco, Cal.

COAHRAN, JESSE MYERS, Professor of Electrical Engineering, Villanova College, Villanova, Pa.

HALL, ARTHUR JOHN, Railway Control Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

JEFFERIES, ERNEST SMITH, Electrical Engineer, Steel Co. of Canada, Hamilton, Ontario.

KEIFER, HAROLD NEIL, Sales Engineer, Northern Electric Co., Vancouver, B. C.

ROCHESTER, THOMAS W., Electrical Engineer, Board of Estimate, New York, N. Y.

VINCENT, H. B., Operating Engineer, Day & Zimmermann, Philadelphia, Pa.

WILLIAMS, SAMUEL BYRON, JR., Telephone Engineer, Western Electric Co., New York, N. Y.

TRANSFERRED TO THE GRADE OF FELLOW MAY 16, 1916

The following Associate was transferred to the Grade of Fellow of the Institute at the meeting of the Board of Directors on May 16, 1916.

FOSTER, WILLIAM J., Designing Engineer, General Electric Co., Schenectady, N. Y.

TRANSFERRED TO THE GRADE OF MEMBER MAY 16, 1916

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on May 16, 1916.

ATKINS, DAVID FOWLER, Chief Engineer, Bureau of Gas and Electricity, Department of Water Supply, Gas and Electricity, New York, N. Y.

COOK, THOMAS R., Chief Engineer, Willard Storage Battery Co., Cleveland, Ohio.

MEMBERS ELECTED MAY 16, 1916

Baldwin, Henry S., Engineer, General Electric Co., West Lynn, Mass.

Baylor, A. K., General Office, General Electric Co., 30 Church St., New York, N. Y.

Cooper, Ashton Burton, Transformer Sales Engineer, Canadian General Electric Co.; res., 133 Albany Ave., Toronto, Ontario.

Hickok, Robert D., President and Engineer, Hickok Electrical Instrument Co., 10514 Dupont Ave., Cleveland, O.

Morelli, Ettore, Professor, Consulting Engineer, Corso Re Umberto 82, Torino, Italy.

Neff, Grover Cleveland, General Superintendent, Wisconsin River Power Co., Southern Wisconsin Power Co., Prairie du Sac, Wis.

Quigley, Louis Leroy, Electrical Engineer, W. A. Clark Properties, Timber Butte Milling Co., Butte, Mont.

Riggs, Arthur Forrest, Assistant to District Engineer, General Electric Co., 1021 Monadnock Bldg., Chicago, Ill.

Woolfolk, William G., Manager, Chicago Office, Sanderson & Porter, 72 West Adams St., Chicago, Ill. Total 9.

ASSOCIATES ELECTED MAY 16, 1916

Ashton, John Oliver, Electrical Engineer, Electric Storage Battery Co., Philadelphia, Pa.; res., 7 Halcyon Pl., Yonkers, N. Y.

Baker, Richard James, Chief Electrician, "Globe" and Commercial Advertiser Ass'n.; res., 2318 Loring Place, New York, N. Y.

Barclay, G. R., Standardizing Laboratory, General Electric Co.; res., 29 Euclid Ave., Schenectady, N. Y.

Benham, Claude Francis, Assistant to the Superintendent of Operation, Great Western Power Co., San Francisco; res., 415 Haight Ave., Alameda, Cal.

Benton, John Robert, Professor of Physics and Elec. Engg. and Dean of the College of Engineering, University of Florida; res., 1650 W. University Ave., Gainesville, Fla.

Breit, Hjalmar Edmund, Chief Electrician, New Jersey Zinc Co. (of Pa.); res., 533 Lafayette Ave., Palmerton, Pa.

Bunch, Charles H., Electric Products Co.; res., 2199 E. 76th St., Cleveland, O.

Busby, John Henry, President, John H. Busby Co. Inc., 73 Shelby St., Detroit, Mich.

Callard, Nathaniel Hearding, Salesman, Westinghouse Electric & Mfg. Co., Salt Lake City, Utah.

Carroll, M. B., Turbine Sales Dept., General Electric Co., Lynn, Mass.

Chu, Fu I., Hanyang Iron Works, Hanyang, China.

Clinton, William Brown, Laboratory Assistant, Standardizing Laboratory, General Electric Co.; res., 150 Front St., Schenectady, N. Y.

Collins, Walter Fillmore, Special Apprentice, Depew Shops, N. Y. C. R. R.; res., 35 Lincoln St., Depew, N. Y.

Corcoran, John Henry, Division Superintendent of Traffic, Pacific Telephone & Telegraph Co., Portland, Ore.

Davis, Frank C., Radio Engineer, U. S. Navy Yard; res., 26 George St., Charleston, S. C.

Edmunds, William Hillsman, Electrical Engineer, Denver & Interurban R. R. Co., 23rd & Market Sts., Denver, Colo.

Egbert, Douglass V., Electrical Draftsman, Engineering Dept., Commonwealth Edison Co., Chicago, Ill.

Fairley, George E. A., Principal Assistant Engineer, Electrical Commission; City Hall, Baltimore, Md.

Fey, William Louis, Supervisor, Electrical Construction, Panama Canal, Balboa Heights, Canal Zone.

Fischer, Robert Henry, Signal Foreman, Panama Railroad Co., Pedro Miguel, Canal Zone.

*FITZHUGH, THOMAS CHAMPE. Dynamo Tender, San Antonio Gas & Electric Co.; res., 620 E. Quincy St., San Antonio, Tex.

FLANDERS, HAROLD WINFRED, Telephone Engineering Dept., Mountain States Tel. & Tel. Co., Denver, Colo.

FUCIK, ROBERT A., Case Man, Illinois Public Utilities Commission, Springfield, Ill.

GLAZE, HENRY C., District Manager, Apparatus Sales, General Electric Co., First National Bank Bldg., Denver, Colo.

GORDON, HARRY E., Telephone Engineer, Rochester Telephone Co.; res., 168 Asbury St., Rochester, N. Y.

GRIMSLEY, ANDREW HOWARD, Chief Engineer and General Manager, Virginia-Western Power Co., Clifton Forge, Va.

HAMLEN, HARRY HOWARD, Plant Dept., American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

HARVEY JOHN L., System Operator, Duquesne Light Co., 435 6th Avenue, Pittsburgh, Pa.

HAYNER, DE ELDON EDWARD, Stone & Webster Engineering Corp., 112 Charles River Road, Cambridge, Mass.

HILL, EDWARD E., General Foreman, Meter Dept., New York Edison Co., 104 E. 32nd St., New York, N. Y.

*HOLCOMBE, WILLIAM E., Designing Engineer, General Electric Co., Schenectady, N. Y.

INGLIS, MALCOLM MACKINNON, Electrical Engineer, Public Utilities Commission, Port Arthur, Ontario, Canada.

JAMES, GEORGE COOPER. In charge of Testing Laboratory, Habirshaw Electric Cable Co., Yonkers, N. Y.

JONES, ARTHUR LUCUS, District Engineer, General Electric Co.; res., 2330 Dexter St., Denver, Colo.

KARDOR, ERNEST. Foreman, Wiring & Assembling Dept., Cooper Hewitt Electrical Co., Hoboken, N. J.; res., 50 W. 117th St., New York, N. Y.

KATSIGRIS, THEODORE C., Electrician, Comet Electric Motor Co., 499 W. Broadway, New York; res., 32 Vernon Ave., Long Island City, N. Y.

KELLOGG, GEORGE HERBERT, Gunner (Electrical), U. S. Navy, U. S. Naval Training Station, San Francisco, Cal.

KELLY, JOHN ALEXANDER, Superintendent of general electrical construction, Martien Electric Co.; res., 1369 Ethel St., Lakewood, Cleveland, O.

KINKEAD, ROBERT EMERSON, Engineer in Electric Arc Welding Dept., Lincoln Electric Co., Cleveland; res., 14 W. Frambes Ave., Columbus, O.

KLUMB, HARVEY JACOB, Meter Engineer, Rochester Railway & Light Co.; res., 279 Clinton Ave. South, Rochester, N. Y.

KOMMERS, OSCAR ANTHONY, District Agent, San Joaquin Light & Power Corp., Corcoran, Cal.

LEESON, WALTER ALBERT, Electrician, Chile Exploration Co., Chuquicamata, Chile, S. A.

LIBBEY, MILES AUGUSTUS, Lieutenant, United States Navy, Navy Department, Washington, D. C.

*LONGENECKER, WARREN BENJAMIN, Instructor, Electrical Engineering, Thaddeus-Stevens Industrial School; res., 24 South Ann St., Lancaster, Pa.

LOPEZ, ERNESTO FELIX, Engineering Staff, J. K. Robinson, Iquique, Chile, S. A.

LUNT, CHARLES FREDERICK, Draughtsman, Braden Copper Co., Rancagua, Chile, S. A.

*MALONEY, CLARENCE JAMES, Sales Engineer, Cutler-Hammer Mfg. Co., 1201 Chestnut St., Philadelphia, Pa.

MANGELS, WALTER C., Chief Load Dispatcher, Public Service Electric Co., Newark; res., 960 Hackensack Plank Road, North Bergen, N. J.

MARKLEY, GEORGE EDGAR, President, Cleveland Electric Motor Co., 5518 Euclid Ave., Cleveland, Ohio.

MAUNDER, HENRY NORRISH, Chief Electrical and Mechanical Engineer, Westport-Stockton Coal Co.'s Electric Railway & Power Plant, Westport, N. Z.

MAUSEAU, CARROLL MILO, Manager, Telephone Cos., Brazilian Traction Co.. Rio de Janeiro, Brazil, S. A.

MAY, WALTER H., Chief Electrician, C. & P. Docks, M. A. Hanna Co., Leader News Bldg., Cleveland, O.

*MCKELVEY, CLINTON FISKE, Equipment Engineer's Assistant, Mountain States Telephone & Telegraph Co.; res., 2842 York St., Denver, Colo.

MERSHON, ALFRED VIVIAN, Laboratory Assistant, Standardizing Laboratory. General Electric Co.; res., 103 Barrett St., Schenectady, N. Y.

MILNER, GEORGE SHERWIN, Manager, Erner Electric Co., Cleveland, O.

MORRIS, JOSEPH F., Engineering Dept., American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

NELSON, J. C., Engineer, Ford, Bacon & Davis, 115 Broadway, New York, N. Y.

NELSON, NELS PETER, Substation Operator, Homestake Mining Co., Lead; res., Central City, S. D.

OBERMAIER, JOHN A., Assistant Testing Engineer, Public Service Co. of Northern Illinois; res., 3044 N. Hamilton Ave., Chicago, Ill.

OLIVER, JAMES MCCAY, Construction and Operation, Alabama Power Co., Birmingham, Ala.

PERIDIER, JULIEN, Chief, Electric Service Dept., Cie. Generale des Omnibus de Paris; res., 16 Rue Cassette, Paris, France.

PROCTOR, ELWYNNE BLAIR, Insurance Engineer, 63 Beaver St., New York, N. Y.

RUECKE, CLARENCE HERMAN, Tester in Engineering Dept., Lincoln Electric Co.; res., 7111 Linwood Ave., Cleveland, Ohio.

SCHERIL, HENRY, Electrical Engineer, Testing Department, Crocker-Wheeler Co., Ampere, N. J.

SCHWARTZ, BEN, Draftsman, Union Electric Light & Power Co.; res., 1337a Semple Ave., St. Louis, Mo.

SCHWARTZ, MICHAEL, Operating Engineer, Automatic Electric Co., Chicago, Ill.

SECOR, HARRY WINFIELD, Managing Editor, *The Electrical Experimenter Magazine*, 233 Fulton St., New York, N. Y.

SHAW, WILLIAM, Electrical Foreman, Galvanizing Dept., National Tube Co.; res., 1606 Library Ave., McKeesport, Pa.

STEWARD, WILLIAM M., Meter Engineer, Elmira Water, Light & Railroad Co.; res., 613 N. Main St., Elmira, N. Y.

STODDARD, ALBERT DOW, Power Despatcher, Kansas City Railways Co; res., 1419 Broadway, Kansas City, Mo.

*STRICKLAND, ROYAL F., Special Lamp Engineer, Lamp Development Laboratory, National Lamp Works of General Electric Co., Nela Park, Cleveland, O.

SULLY, SULPEN, Elevator Constructor, Eastern Machinery Co.; res., 53 Lake Place, New Haven, Conn.

SULTZER, PAUL O., Draftsman, Montana Power Co.; res., 631 W. Quartz St., Butte, Mont.

SUMMER, MUREL ADAM DANFORD, District Manager, Pittsburgh Transformer Co., 601 Electric Building, Buffalo, N. Y.

*TAIT, IRVING R., Electrical Engineer, Engineering Dept., Canadian Explosives Ltd.; res., 288 De L'Epee Ave., Montreal, Quebec.

TAYLOR, VERNE ELWOOD, Assistant Chief Electrician, N. Y., N. H. & H. R. R. Co., Cos Cob; res., 3 Willow Court, Stamford, Conn.

THIRLWALL, JOHN CONNOP, Engineer, Railway & Traction Dept., General Electric Co., Schenectady, N. Y.

WALTON, HARRY MOORE, Construction Foreman, General Electric Co., Atlanta, Ga.

WEIGHTMAN, HUGH EDWARD, Consulting Engineer, 2035 North Kedzie Ave., Chicago, Ill.

WESTPHAL, HERMAN CHARLES, Superintendent, Jersey Shore Electric Co., Jersey Shore, Pa.

WHEAT, GEORGE J., Assistant to Supt. of Operation and Maintenance, Paci-

fic Gas & Electric Co.; res., 3328 Elm St., Oakland, Cal.

*YANG, SIH-ZUNG, Chief Engineer, Far Eastern Div., Gaston, Williams & Wigmore Inc.; res., 417 W. 118th St. New York, N. Y.

YODER, CLAYTON PHELPS, In charge of Standardizing Laboratory, General Electric Co., Erie, Pa.

Total 83.

*Former enrolled Students.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before June 30, 1916.

Andrews, R. M., Parkersburg, W. Va.
Baer, L. E., St. Paul, Minn.
Bartlett, H. W. (Member), Ione, Cal.
Baswell, W. O., Toronto, Ont.
Bower, J. R., Berwick, Pa.
Brundage, D. C., New York, N. Y.
Burgeson, E. B., Parlin, N. J.
Butz, C. H., Denver, Colo.
Clements, C. J., Cleveland, O.
Conner, J. L., South Bethlehem, Pa.
Corey, J. W., Cleveland, O.
Creveling, A. B., Walla Walla, Wash.
Day, A. B. (Member), Los Angeles, Cal.
Depweg, L. S., Norwood, O.
Dixon, J. L., Detroit, Mich.
Ellison, L. H., Chicago, Ill.
Emmons, O. J., Chicago, Ill.
Fisher, E. A., New York, N. Y.
Fitz, E. S., Pawtucket, R. I.
Foote, J. B., Jackson, Mich.
Freeman, F. S., Boston, Mass.
Garrett, W. W., Jr., Ensley, Ala.
Gooch, E. C., Schenectady, N. Y.
Gregory, J. E., Cleveland, O.
Hadcock, J. P., Peterboro, Ont.
Haigh, P. N., Barberton, O.
Haveson, H., Trenton N. J.
Hays, L. K., Clearfield, Pa.
Hinrichs, E., Pearce, Ariz.
Jones, C. A. (Member), New York, N.Y.
Kennedy, O. W., East Pittsburgh, Pa.
Lowell, R. T. S., Washington, D. C.
Mackintosh, C., Pedro Miguel, C. Z.
Matthews, E. M., New York, N. Y.
Meissner, E. B., St. Louis, Mo.
Morehouse, L. F. (Member), New York, N. Y.
Nicholas, F., New York, N. Y.
Oliver, S. L., Clinton, N. C.
O'Ryan, F., Denver, Colo.
Patterson, R. F., McKees Rocks, Pa.
Pillay, P. S., Madras, South India.
Pollock, R. T., Indianapolis, Ind.
Purtee, L. G., Oklahoma City, Okla.
Read, W. G., Topeka, Kans.
Roberts, T. C. (Member), Clarkdale, Ariz.
Rutherford, R. O., Los Angeles, Cal.
Rutledge, T. W., Cleveland, O.
Schultz, G. E., New York, N. Y.
Scott, H. M., Pittsburgh, Pa.
Shaw, C. H., Sheboygan, Wis.
Shepard, E. M., Jr., Detroit, Mich.
Steiert, R. B., Fellows, Cal.
Stone, O. R., Augusta, Me.
Stirling, H. H., Ensley, Ala.
Street, G. T. (Member), Youngstown, O.
Sumner, C. L., Jr., San Francisco, Cal.
Tallmadge, E. S., St. Paul, Minn.
Tays, E., Benicia, Cal.
Ten Haagen, J. E., Chicago, Ill.
Tosaku, F., Tokyo, Japan
Tuck, F. W., Giant, Cal.
Wagner, C. F., Atlanta, Ga.
Wallace, E. P., Kansas City, Mo.
Weeks, R. W., New York, N. Y.
Weller, F. R. (Member), Washington, D. C.
Woolfenden, H. L., Denver, Colo.
Worthing, E. E. (Member), Houston, Tex.
Winne, H. A., Schenectady, N. Y.
Yarrington, C. A., Baltimore, Md.

Total 69.

STUDENTS ENROLLED MAY 16, 1916

8136 Shirk, D. R., Lewis Institute
8137 Knickerbocker, W. G., Michigan Agricultural College
8138 Edelman, P. E., Univ. of Minn.
8139 Underwood, W. H., Wentworth Inst

8140 Sanford, C. H., Wentworth Inst.
8141 Nicholson, J. H., Univ. of Pitts.
8142 Burt, F., Univ. of Minnesota.
8143 Elkins, L. H., Worcester Poly Inst.
8144 Smelser, W. A., Univ. of Toronto.
8145 Weppler, H. S., Univ. of Toronto.
8146 Nelles, R. H., Univ. of Wash.
8147 Norman, H. P., Bucknell Univ.
8148 Reiber, A. H., Stevens Inst. Tech.
8149 Stearns, E., Wentworth Inst.
8150 Swett, L. W., Univ. of Illinois.
8151 Peers, G. A., Stanford Univ.
8152 Smith, J. R., Univ. of Minnesota.
8153 Coburn, L. F., Mich. Agri. Coll.
8154 Stoos, F., Univ. of North Dakota.
8155 Burns, F. W., Univ. of N. Dakota.
8156 Hussey, J. A., Univ. of N. Dakota.
8157 Whitcomb, A. J., Univ. of N. D.
8158 Roth, W., Univ. of Washington.
8159 Lingle, R. W., Univ. of Calif.
8160 Stock, W. J., Purdue University.
8161 Wells, G. H., Purdue University.
8162 Covell, R. O., Univ. of Minn.
8163 Meier, J. C., N. Y. Elec. Sch.
8164 Brower, L. W., Brown University.
8165 Blair, J. A., Worcester Poly Inst.
8166 Monici, S., Ohio Northern Univ.
8167 Guimaraes, A. de S. M., Ohio Northern University.
8168 Moran, R. B., Colo. Agri. College.
8169 Niepp, F. A., Stanford University.
8170 McCue, F. F., Clarkson Coll. Tech.
8171 Keiser, D. S., Univ. of Penna.
8172 Morris, C. F., Univ. of Wash.
8173 Riddell, L. A., Univ. of Pittsburgh
8174 Weaver, T. D., Univ. of Michigan
8175 Hibner, R. F., Penna. State Coll.
8176 Aiken, M. K., Ga. School of Tech.
8177 Johnson, J. F., Univ. of Wisconsin
8178 Ryan, C. L., Univ. of Nebraska.
8179 Thompson, H. T., Univ. of Minn.
8180 Chandler, F. D., Mass. Inst. of Tech.
8181 Hodges, J. S., Univ. of Colorado.
8182 Parkerson, L. R., Kansas State Agricultural College.
8183 Ludden, H. J., Univ. of Wisconsin
8184 Shrigley, E., N. Y. Elec. School.
8185 Overpeck, J. H., Rose Poly. Inst.
8186 Chan, S. W., Pratt Institute.
Total 51.

EMPLOYMENT DEPARTMENT

Note: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-133. Mechanical Draftsman. One with some shop experience and knowledge of shop technique. The work requires a man of some originality and includes designs of small machines, detailing of repair parts for hydraulic presses and pumps, as well as the layout of high-pressure lines, and enough skill to select and adapt conveyors from manufacturers' catalogs. Salary to start $125.

V-134. Young technical graduate required for temporary work, duration about four months, to act as assistants in making appraisals of telephone properties for public service commission. Prefer men with valuation experience. $75-$125 per month.

V-135. Recent technical graduate with General Electric testing department experience, wanted by a testing and inspecting company. A man who makes a good impression, has a good college record and has aptitude for laboratory work preferred. State full particulars as to technical training, experiecne, salary expected and give references, both character and technical.

V-136. Engineering Draftsman and Detailer. Mechanical and electrical central station work. Must be technical graduate; salary $120 per month.

V-137. Draftsman. General mechanical and electrical work. Technical graduate preferred. Salary $110 per month.

V-138. Draftsman. General mechanical and electrical work. Technical graduate preferred. Salary $95 per month

V-139. Draftsman. General mechanical and electrical work. Technical graduate preferred. Salary $85 per month.

V-140. A good opportunity is afforded one having a thorough knowledge of the design and application of high and low tension oil switches. Only those having had actual experience will be considered. State briefly qualifications and references.

V-141. A good opportunity is afforded one having a thorough knowledge of the design and application of carbon-break circuit breakers. Only those having had actual experience will be considered. State briefly qualifications and references.

A U. S. Civil Service examination will be held for Junior Electrical Engineer on June 21, at numerous places in the U. S., to fill vacancies in the Bureau of Mines, Pittsburgh, at salaries ranging from $960 to $1200 a year.

Persons who desire this examination should apply at once for the circular announcing this examination (Form No. 677, issued May 11, 1916) and Form No. 1312, stating the title of the examination for which the form is desired, to the U. S. Civil Service Commission, Washington, D. C., or if time is limited application may be made at the nearest post office or customhouse at any of the numerous places in the U. S. where the examination will be held.

MEN AVAILABLE

495. Laboratorian and Electrical Draftsman. Two years' experience and in charge of electrical test laboratory large light and power company; eight months of various drafting experience; six months department inspection and testing, large electrical manufacturing company; other experience. Graduate E. E.; age 27; salary moderate; similar or sales work desired.

496. Technical Graduate (B.S.E.E.) Expert on d-c., a-c. and high-tension watt-hour meters; wide experience in the testing, inspection and manufacture of insulated cable; well qualified to take charge of electrical standardizing laboratory; illuminating engineering; appraisal of lighting companies' plants; testing and inspection of railroad equipment of N. Y. City systems. Age 27; single; now employed. Location no object. Salary $1500.

497. Car Lighting Engineer, age 30, desires change. Technical graduate. Five years' engineering experience in operation and testing of car lighting equipment with one of the largest roads in the East. Available immediately.

498. Technical Graduate with four years' test experience on motors, generators, transformers and watt-hour meters, desires a position with consulting or construction engineers; available at short notice; no objection to locality.

499. As Chief Electrician or Assistant Electrical Engineer of industrial plant in or near New York City. Large experience in individual motor application and calculating, planning and installing power distribution. Resourceful and possesses good constructive ability. Can plan, install and maintain successfully entire electrical equipment. Good executive ability. Have handled and directed men with best of results. Would accept position with growing power station.

500. Powerful Young American, proved inventive ability and business sense; progressive research methods, knows patents; special knowledge of radio-communication; writer with international reputation; university graduate; strong character. Desires connection with progressive manufacturer starting research department or with research engineer of reputation. Salary no object.

501. Graduate Electrical Engineer, now employed, seeks connection where executive capacity, knowledge of technical efficiency, cost and storeroom methods, ability for handling men and the possesssion of a pleasing personality are prerequisites. Seven years' experience in electrical machine design and central station design and operation. Minimum salary $2500.

502. Electrical Engineer, age 27, 1916 technical graduate, with degree. Desires position with contractor or illuminating engineer. Would accept position with industrial or railroad company. Good character, salary moderate. East preferred.

503. Hydraulic-Electrical Engineer, university graduate, with thirteen years' experience on large hydroelectric installation, design and manufacture of pumping machinery, mechanical design and salesmanship. Age 36, energetic, and with a very thorough training.

504. Steam and Electrical Engineer, twelve years' experience, desires change about July 1. Technical education. Qualified to superintend plant operation. Can handle men and expenditures with paying results. Age 30. correspondence invited.

505. Civil and Hydraulic Engineer. Age 30; six years' experience in design and construction irrigation, power and pumping; desires immediate responsible position, manager or engineer. Sound technical training; experience handling men on dam, pipe line, power house and canal construction. Present salary $150.

506. Mechanical-Electrical Engineer, Chief Electrician, Master Mechanic. Age 35; practical, technical, executive, organizer. Fifteen years with telephone, railroad, smelter and mining companies. Absolutely clear record; desires position of responsibility and trust with going industrial, railroad, mining or smelting corporation. Present salary $2400.

507. Electrical Engineer, age 31, married; with six years' experience in design of hydroelectric stations, substations, transmission lines, switches, etc., desires responsible position in the West. Thoroughly familiar with both the technical and practical side of testing transformers, switches, meters, relays, etc. Minimum salary $1800.

508. Electrical Engineer, age 36, technical graduate, degree of E. E. Fel. A. I. E. E. Wishes responsible position with operating company. Has had two years' experience in G. E. test and fourteen years' experience in construction and operation in U. S. and abroad. Wide experience in all phases of generating plants, transmission lines, lighting, motor application, etc. Willing to go anywhere. Speaks Spanish fluently and familiar with Portuguese, French and German.

509. Electrical Engineer, technical graduate, age 25. Five years' all-around experience. Now employed in engineering department of large electrical manufacturing concern. Wishes to take up manufacturing or experimental work. Moderate initial salary with good prospects. Available early in July.

510. Electrical Engineer, technical graduate, age 38, married. Sixteen years' domestic and foreign experience in engineering, construction and operation of railway, lighting and power stations, and overhead and underground distribution systems. Familiar with estimates, contracts, specifications, etc.

511. High School Graduate, student New York electrical school evening course, age 19, no electrical experience, wishes employment with opportunity to learn electrical business. At present in stock-brokerage office.

512. Construction Electrician with technical education and a varied experience in construction work. Age 37. Has handled crews up to 200 men.

ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Illinois. State Public Utilities Commission. Annual Report, First. Vols. I-II. Springfield, 1914. (Gift of Commission)

Maryland Public Service Commission. Report, 1915. Baltimore, 1916. (Gift of Public Service Commission).

United Engineering Society

Alternating-Current Electricity and its Applications to Industry. Second Course. By W. H. Timbie and H. H. Higbie. New York, J. Wiley & Sons, 1916. Price $3.00 net. (Gift of Publishers).

A textbook, with numerous problems for students. W.P.C

Circular of William A. Orcutt, manufacturer of Orcutt's Patent Lightning Rods. Boston, 1866. (Purchase.)

Instruments for Recording Carbon Dioxide in Flue Gases. (U. S. Bureau of Mines, Bulletin 91). Washington, 1916. (Purchase.)

International Engineering Congress, 1915. Transactions. Vol. VII, Electrical Engineering and Hydroelectric Power Development. San Francisco, 1915. (Purchase.)

National Electric Light Association. List of company members Jan. 1, 1916. New York, 1916. (Purchase.)

Stationsdeckungs und Blocksignale. By A. Gutzwiller. Zurich, 1915. (Purchase.)

Gift of Hyatt Roller Bearing Company

Electrical World, vols. 22-24, 1893-4.
Electrician, vols. 26-33, 1890-94.
Engineering Mechanics, vol. 13, 1891.

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DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
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C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.

*Deceased.

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Revised to June 1, 1916

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Revised to June 1, 1916

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Revised to June, 1916

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Ampere, N. J.
Ralph D. Mershon, Frank J. Sprague.

Term expires July 31, 1917.
A. E. Kennelly, Robert T. Lozier.
S. G. McMeen.

Term expires July 31, 1918.
H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.
Charles F. Brush, William Stanley.
N. W. Storer.

Term expires July 31, 1920.
Carl Hering, Harris J. Ryan,
H. G Stott.

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Term expires July 31, 1916.
C. O. Mailloux, L. T. Robinson,
Farley Osgood.

Term expires July 31, 1917.
B. A. Behrend, Paul M. Lincoln
William McClellan.

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Farley Osgood, F. B. H. Paine,
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Revised to June 1, 1916.

Name and when Organized	Chairman	Secretary
Atlanta...............Jan. 19, '04	A. M. Schoen	H.E. Bussey, 3d Nat. Bk. Bldg. Atlanta, Ga.
Baltimore..............Dec. 16, '04	J. B. Whitehead	L. M. Potts Industrial Bldg, Baltimore, Md.
Boston................Feb. 13, '03	L. L. Elden	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago......................1893	W. J. Norton	Taliaferro Milton, 613 Marquette Building, Chicago, Ill.
Cleveland.............Sept. 27, '07	E. H. Martindale	Irving H. Van Horn, National Lamp Works, Nela Park, Cleveland, Ohio.
Denver................May 18, '15	W. A. Carter	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor......Jan. 13, '11	Ralph Collamore	C. E. Wise, 427 Ford Bldg., Detroit, Mich.
Fort Wayne...........Aug. 14, '08	J. J. Kline	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Ind.
Indianapolis-Lafayette...Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca.................Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Kansas City, Mo........Apr. 14, '16	Gordon Weaver	Glenn O. Brown, Kansas City Elec. Lt. Co., Kansas City, Mo.
Los Angeles...........May 19, '08	E. Woodbury	R. H. Manahan, 32 City Hall, Los Angeles, Cal.
Lynn..................Aug. 22, '11	G. N. Chamberlin	F. S. Hall, Gen.Elec.Co., West Lynn, Mass.
Madison...............Jan. 8, '09	M. C. Beebe	F. A. Kartak, Univ. of Wis., Madison, Wis
Mexico................Dec. 13, '07		
Milwaukee..............Feb. 11, '10	R. B. Williamson	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.............Apr. 7, '02	E. T. Street	Walter C. Beckjord, St. Paul Gas Light Co., St. Paul, Minn.
Panama................Oct. 10, '13	William H. Rose	C. W. Markham, Balboa Heights, C. Z.
Philadelphia...........Feb. 18, '03	J. H. Tracy	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh.............Oct. 13, '02	T. H. Schoepf	G. C. Hecker, 436 Sixth Avenue, Pittsburgh, Pa.
Pittsfield..............Mar. 25, '04	M. O. Troy	F. R. Finch, General Electric Company, Pittsfield, Mass.
Portland, Ore...........May 18, '09	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Rochester..............Oct. 9, '14	E. L. Wilder	F. E. Haskell, 93 Monica Street Rochester New York.
St. Louis...............Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco.........Dec. 23, '04	A. H. Babcock	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady...........Jan. 26, '03	L. T. Robinson	F. W. Peek, Jr., Gen. Elec. Co., Schenectady, N. Y.
Seattle................Jan. 19, '04	C. E. Magnusson	C. F. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Spokane...............Feb. 14, '13	Victor H. Greisser	C. A. Lund, Washington Water Power Co., Spokane, Washington.
Toledo.................June 3, '07	W. E. Richards	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto................Sept. 30, '03	H. T. Brandon	Wills Maclachlan, 910 Excelsior Life Building, Toronto, Ont.
Urbana.................Nov. 25, '02	P. S. Biegler	T. D. Yensen, Univ. of Illinois, Urbana, Ill.
Vancouver..............Aug. 22, '11	R. F. Hayward	H. N. Keifer, Northern Electric Company, Ltd., Vancouver, B. C.
Washington, D. C.......Apr. 9, '03	R. H. Dalgleish	Arthur Dunlop, National Electric Supply Company, Washington, D. C.

Total 33

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas......Nov. 12, '09	A. Dickie	G. B. Hanson.
Alabama, Univ. of......Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of......Mar. 25, '04	A. L. Wilson	W. L. Teague, University of Arkansas, Fayetteville, Ark.
Armour Institute........Feb. 26, '04	A. A. Oswald	J. F. Hillock, Armour Institute of Technology, Chicago, Ill.
Brooklyn Poly. Inst.,...Jan. 14, '16	Albert H. Bernhard	Walter J. Seeley, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University....May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	Marc Holzer	C. Maynard, University of California, Berkeley, Cal.
Carnegie Inst. of Tech..May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.....Apr. 10, '08	W. A. Steward	R. H. Kruse, 75th and Main Streets, Cincinnati, Ohio.
Clarkson Col. of Tech...Dec. 10, '15	W. A. Dart	C. J. Dresser, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col. Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College.........Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized		Chairman	Secretary
Colorado, Univ. of	Dec. 16, '04	E. F. Peterson	Samuel J. Blythe, University of Colorado, Boulder, Colo.
Georgia School of Technology	June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College	Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of	June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College	Apr. 15, '03	F. H. Hollister	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of	May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col.	Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agric. Col., Manhattan, Kansas.
Kansas, Univ. of	Mar. 18, '08	N. M. Foster	G. M. Bowman, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of	Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College	Apr. 5, '12	Rodman Fox	Frank H. Schlough, Lafayette College, Easton, Pa.
Lehigh University	Oct. 15, '02	A. F. Hess	R. W. Wiseman, Lehigh University, South Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of	Dec. 26, '06	A. A. Packard	E. V. Crimmin, Univ. of Maine, Orono, Me.
Michigan, Univ. of	Mar. 25, '04	U. M. Smith	N. F. Brown, University, of Michigan Ann Arbor, Mich.
Minnesota, Univ. of	May 16, '16	Jesse L. Thompson	Donald P. Loye, 4216 Dupont Ave., South, Minneapolis, Minn.
Missouri, Univ. of	Jan. 10, '03	K. Atkinson	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col.	May 21, '07	Taylor Lescher	J. A. Thaler Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts	Feb. 11, '10	R. V. Davis	R. L. Kelly, West Raleigh, N. C.
North Carolina, Univ. of	Oct 9. '14	Edw. Y. Keesler	W. H. Joyner, Univ. of North Carolina, Chapel Hill, N. C.
Ohio Northern Univ.	Feb. 9, '12	H. H. Robinson	F. W. Evans, 302 E. Lincoln Avenue, Ada, Ohio.
Ohio State Univ.	Dec. 20, '02	R. G. Locket	D. A. Dickey, Ohio State University, Columbus, Ohio.
Oklahoma, Agricultural and Mech. Col.	Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of	Oct. 11, '12	Clifford O. Oster	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon Agr. Col.	Mar. 24, '08	Winfield Eckley	J. A. Hooper, Oregon Agric. College, Corvallis, Ore.
Penn. State College	Dec. 20, '02	C. L. Knotts	William W. Herold, Jr., State College, Pa.
Pittsburgh, Univ. of	Feb. 26, '14	G. R. Patterson	W. K. Benz, University of Pittsburgh, Pittsburgh, Pa.
Purdue University	Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Rensselaer Poly. Inst.	Nov. 12, '09	W. J. Williams	S. N. Galvin, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst.	Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col.	Mar. 14, '13	C. E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ.	Dec. 13, '07	A. B. Stuart	H. J. Rathbun, Stanford University, Cal.
Syracuse Univ.	Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of	Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin, Tex.
Throop College of Technology	Oct. 14, '10	J. W. DuMond	K. W. Rich, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute	Jan. 8, '15	V. Dixon	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of	Feb. 9, '12	W. S. Rodman	J. H. Moore, Dawsons Row, University, Va.
Wash. State Col. of	Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Coll. of Wash. Pullman, Wash.
Washington Univ.	Feb. 6, '04	P. C. Roberts	Charles A. Lieber, Washington University, St. Louis, Mo.
Washington Univ. of	Dec. 13, '12	E. C. Miller	Geo. S. Smith, Univ. of Washington, Seattle, Wash.
West Virginia Univ.	Nov. 13, '14	H. C. Schramm	C. L. Walker, West Virginia Univ., Morgantown, W. Va.
Worcester Poly. Inst.	Mar. 25, '04	R. M. Thackeray	C. C. Whipple, Worcester Polytechnic Institute, Worcester, Mass.
Yale University	Oct. 13, '11	A. W. Cahoon	J. P. Allen, Sheffield Scientific School, New Haven, Conn.

Total 55.

To be presented at the 317th meeting of the American Institute of Electrical Engineers, New York, January 14, 1916.

OUTLINE OF THEORY OF IMPULSE CURRENTS

BY CHARLES P. STEINMETZ

ABSTRACT OF PAPER

In Part I it is shown how, from the integral of the general differential equation of the electric circuit, which has been discussed in a previous paper, all the types of electric currents are derived as special cases, corresponding to particular values of the integration constants.

The equations of the circuits with massed constants, that is, the usual electric circuits, are derived by substituting zero for the (electrical) length of the circuit.

Besides the general transients, discussed in a previous paper, three main classes of currents are shown to exist, corresponding to different values of the time exponent b:

The alternating currents, corresponding to b = imaginary, which are the useful currents of our electric circuits.

The impulse currents, corresponding to real values of b, which may be called harmful currents of our electric circuits.

And, as limit case, for $b = 0$, the continuous-current circuit with distributed constants.

The last case, a continuous current in a circuit with distributed resistance and leakage, is discussed, and it is shown that such continuous-current circuit has many features which are usually considered as typical of alternating-current wave transmission. It consists of a main current and a return current; complete reflection occurs at the end of the circuit; partial reflection at a transition point; a surge resistance exists, which, connected to the circuit, passes the current without reflection.

In Part II an outline of the theory of impulse currents is given. They comprise two classes, the non-periodic and the periodic impulse currents. The equations of both are given in different form, by exponential and by hyperbolic or trigonometric functions. Their characteristics are:

Impulse current and voltage may be resolved into a main wave and a return wave. The return wave is displaced from the main wave in time and in position. A time displacement exists between the two current waves and their corresponding voltage waves. This time displacement may be a lag of the current behind the voltage, or a lead, depending on the circuit constants. In the periodic impulse currents, the displacement between main wave and return wave is represented by a position angle, and the two current waves are in quadrature in position, to their respective voltage waves.

A few special cases are discussed.

Manuscript of this paper was received December 10, 1915.

I. TYPES OF CURRENT

A. General

If

r = resistance
g = shunted conductance
L = inductance
C = capacity

per unit length of any circuit or section of a circuit, then in any line element dl of the circuit, the voltage consumed is

$$\frac{d\,e}{d\,l} = ri + L\,\frac{di}{dt} \tag{1}$$

and the current consumed is

$$\frac{d\,i}{d\,l} = g\,e + C\,\frac{d\,e}{d\,t} \tag{2}$$

Differentiating (1) over dt, and (2) over dl, and combining gives

$$\frac{d^2i}{dl^2} = LC\,\frac{d^2i}{dt^2} + (r\,C + g\,L)\,\frac{d\,i}{d\,t} + r\,g\,i \tag{3}$$

Integrating,

$$i = A\,\epsilon^{-al}\,\epsilon^{-bt} \tag{4}$$

$$e = \frac{b\,L - r}{a}\,A\,\epsilon^{-al}\,\epsilon^{-bt} \tag{5}$$

$$= \sqrt{\frac{b\,L - r}{b\,C - g}}\,A\,\epsilon^{-al}\,\epsilon^{-bt}$$

$$= z\,i$$

where

$$z = \sqrt{\frac{b\,L - r}{b\,C - g}} \tag{6}$$

is the *surge impedance* or *natural impedance* of the circuit, and a and b are related by the equation

$$a^2 = b^2 LC - b\ (r\ C + g\ L) + rg \tag{7}$$

$$= (bL - r)\ (bC - g)$$

The general solution then is a sum of such terms (**4**) and (**5**).

These equations must represent every existing electric circuit, and every circuit which can be imagined, from the lightning discharge to the house bell, and from the alternating-current transmission line to the telephone circuit, with the only limitation, that r, g, L, C are constant within the range of the currents and voltages considered.

The difference between all electric circuits thus merely consists in the difference of the constants A, a and b, and the difference in the length l of the circuit.

If $l = 0$, that is, the length of the circuit is negligible compared with the rate of change of i or e, (**4**) and (**5**) give the equations of all the circuits with massed constants, otherwise we get the equations of the circuits with distributed constants.

In general, a and b are general numbers, related to each other as in (**7**). Choosing b as the independent constant,

$b = 0$ gives the continuous currents.
$b =$ real gives the impulse currents.
$b =$ imaginary gives the alternating currents.
$b =$ general or complex imaginary gives the general transients.
$b = 0$ or imaginary thus gives the *permanents*, continuous current and alternating current.
$b =$ real or general gives the *transients*, impulse currents and general transients.

Thus, while the continuous currents represent a limiting case, the alternating currents and the impulse currents are two coordinate classes of currents. While the alternating currents are the useful currents of our electric systems, the impulse currents may be said to be the harmful currents in our systems, as many of the disturbances and troubles in electric systems are caused by them.

The theory of alternating currents is discussed in numerous publications, but little systematic study has been made of the impulse currents, and their general theory thus will be given in the following, and also that of the limiting case of the continuous

currents in a general circuit of distributed constants. The theory of the general transients has been outlined in a previous paper.*

B. Circuits with Massed Constants

Substituting in (**4**) and (**5**):

$$e = 0 \text{ when } l = 0$$

and considering that, by equation (**7**), a can have two values, for every value of b, $+ a$ and $- a$, we have,

$$\begin{aligned} i &= A \epsilon^{-bt} \{\epsilon^{-al} + \epsilon^{+al}\} \\ e &= \frac{bL - r}{a} A \epsilon^{-bt} \{\epsilon^{-al} - \epsilon^{+al}\} \end{aligned} \tag{8}$$

Assuming now l as infinitely small, and substituting

$$\epsilon^{\pm al} = 1 \pm a\,l \tag{9}$$

in (**8**), gives, as the general equation of the circuit with massed constants,

$$\begin{aligned} i &= B \epsilon^{-bt} \\ e &= (r_0 - bL_0) B \epsilon^{-bt} \end{aligned} \tag{10}$$

where

$B = 2A$

$r_0 = l\,r =$ total resistance of circuit,

$L_0 = l\,L =$ total inductance of circuit.

Substituting $b = 0$ in (**10**), gives

$$\begin{aligned} i &= B \\ e &= r_0 B \end{aligned} \tag{11}$$

as the equation of the continuous-current circuit.

For $b =$ real (**10**), the equations of the inductive discharges are

$$\begin{aligned} i &= B \epsilon^{-bt} \\ e &= (r_0 - bL_0) B \epsilon^{-bt} \\ &= r_0 i + L_0 \frac{di}{dt} \end{aligned} \tag{12}$$

*A. I. E. E. Transactions 1908, page 1231, and more completely in Section IV of "Transient Phenomena."

Substituting $b = \pm j\,c$ gives as the equation of the alternating-current circuit,

$$i = C_1 \cos ct + C_2 \sin ct$$
$$e = (r_0\,C_1 - c\,L_0\,C_2)\cos ct + (r_0\,C_2 + cl_0\,C_1)\sin ct \qquad \textbf{(13)}$$

where

$$C_1 = B_1 + B_2$$
$$C_2 = j\,(B_1 - B_2) \qquad \textbf{(14)}$$

C. Continuous-Current Circuit with Distributed Constants

$$b = 0$$

From (**7**) we have

$$a = \pm\sqrt{rg} \qquad \textbf{(15)}$$

and from (**6**),

$$z = \pm\sqrt{\frac{r}{g}} \qquad \textbf{(16)}$$

substituting (**15**) and (**16**) in (**4**) and (**5**) gives

$$i = A_1\,\epsilon^{-l\sqrt{rg}} + A_2\,\epsilon^{+l\sqrt{rg}} \qquad \textbf{(17)}$$

$$e = \sqrt{\frac{r}{g}}\,\{A_1\,\epsilon^{-l\sqrt{rg}} - A_2\,\epsilon^{+l\sqrt{rg}}\} \qquad \textbf{(18)}$$

These equations do not contain L and C, that is, inductance and capacity have no effect on the permanent continuous-current circuit with distributed constants, but only resistance and conductance, that is, leakage.

Equations (**17**) and (**18**) are the equations of a direct-current circuit having distributed leakage, such as a metallic conductor submerged in water, or the current flow in the armor of a cable laid in the ground, or the current flow in the rail return of the direct-current railway, etc.

r is the series resistance per unit length, g the shunted or leakage conductance per unit length of circuit.

Where the leakage conductance is not uniformly distributed, but varies, the numerical values in (**18**) change wherever the circuit constants change, just as would be the case if the resistance r of the conductor changed. If the leakage conductance g is not uniformly distributed, but localized periodically in space —as at the ties of the railroad track,—when dealing with a sufficient circuit length, the assumption of uniformity would be justified as an approximation.

(a) If the conductor is of infinite length—that is, of such great length, that the current which reaches the end of the conductor, is negligible compared with the current entering the conductor, we have

$$A_2 = 0$$

This gives

$$\begin{aligned} i &= A\, \epsilon^{-l\sqrt{rg}} \\ e &= A \sqrt{\frac{r}{g}}\, \epsilon^{-l\sqrt{rg}} \end{aligned} \qquad (19)$$

or

$$e = \sqrt{\frac{r}{g}}\, i \qquad (20)$$

that is, a conductor of infinite length (or very great length) of series resistance r and shunted conductance g, has the effective resistance $r' = \sqrt{\frac{r}{g}}$.

It is interesting to note, that at a change of r or of g the effective resistance r', and thus the current flowing into the conductor at constant impressed voltage, or the voltage consumed at constant current, changes much less than r or g.

(b) If the circuit is open at $l = l_0$, we have

$$i = A_1\, \epsilon^{-l_0\sqrt{rg}} + A_2\, \epsilon^{+l_0\sqrt{rg}} = 0$$

Hence, if

$$A = A_1\, \epsilon^{-l_0\sqrt{rg}} = -A_2\, \epsilon^{+l_0\sqrt{rg}}$$

we have

$$\begin{aligned} i &= A \left\{ \epsilon^{+(l_0-l)\sqrt{rg}} - \epsilon^{-(l_0-l)\sqrt{rg}} \right\} \\ e &= A \sqrt{\frac{r}{g}} \left\{ \epsilon^{+(l_0-l)\sqrt{rg}} + \epsilon^{-(l_0-l)\sqrt{rg}} \right\} \end{aligned} \qquad (21)$$

(*c*) If the circuit is closed upon itself at $l = l_0$, we have

$$e = \sqrt{\frac{r}{g}}\,\{A_1\,\epsilon^{-l_0\sqrt{rg}} - A_2\,\epsilon^{+l_0\sqrt{rg}}\} = 0$$

Hence, if

$$A = A_1\,\epsilon^{-l_0\sqrt{rg}} = A_2\,\epsilon^{+l_0\sqrt{rg}}$$

we have

$$\begin{aligned} i &= A\,\{\epsilon^{+(l_0-l)\sqrt{rg}} + \epsilon^{-(l_0-l)\sqrt{rg}}\} \\ e &= A\sqrt{\frac{r}{g}}\,\{\epsilon^{+(l_0-l)\sqrt{rg}} - \epsilon^{-(l_0-l)\sqrt{rg}}\} \end{aligned} \qquad \textbf{(22)}$$

If, in (**22**), $l_0 = 0$, that is, the circuit is closed at the starting point, we have

$$i = A\,\{\epsilon^{-l\sqrt{rg}} + \epsilon^{+l\sqrt{rg}}\}$$

$$e = A\sqrt{\frac{r}{g}}\,\{\epsilon^{-l\sqrt{rg}} - \epsilon^{+l\sqrt{rg}}\}$$

or, counting the distance in opposite direction, that is, changing the sign of l

$$\begin{aligned} i &= A\,\{\epsilon^{+l\sqrt{rg}} + \epsilon^{-l\sqrt{rg}}\} \\ e &= A\sqrt{\frac{r}{g}}\,\{\epsilon^{+l\sqrt{rg}} - \epsilon^{-l\sqrt{rg}}\} \end{aligned} \qquad \textbf{(23)}$$

(*d*) If the circuit, at $l = l_0$, is closed by a resistance r_0, we have

$$\left|\frac{e}{i}\right|_{l=l_0} = r_0$$

hence,

$$\frac{A_1\,\epsilon^{-l_0\sqrt{rg}} - A_2\,\epsilon^{+l_0\sqrt{rg}}}{A_1\,\epsilon^{-l_0\sqrt{rg}} + A_2\,\epsilon^{+l_0\sqrt{rg}}} = \frac{r_0}{\sqrt{\frac{r}{g}}}$$

$$\frac{A_2\,\epsilon^{+l_0\sqrt{rg}}}{A_1\,\epsilon^{-l_0\sqrt{rg}}} = \frac{\sqrt{\frac{r}{g}} - r_0}{\sqrt{\frac{r}{g}} + r_0}.$$

or,

$$A_2 = A_1\,\epsilon^{-2 l_0 \sqrt{rg}}\,\frac{\sqrt{\frac{r}{g}} - r_0}{\sqrt{\frac{r}{g}} + r_0} \tag{24}$$

$$\left.\begin{aligned} i &= A\left\{\epsilon^{-l\sqrt{rg}} - \frac{r_0 - \sqrt{\frac{r}{g}}}{r_0 + \sqrt{\frac{r}{g}}}\,\epsilon^{-(2 l_0 - l)\sqrt{rg}}\right\} \\ e &= A\sqrt{\frac{r}{g}}\left\{\epsilon^{-l\sqrt{rg}} + \frac{r_0 - \sqrt{\frac{r}{g}}}{r_0 + \sqrt{\frac{r}{g}}}\,\epsilon^{-(2 l_0 - l)\sqrt{rg}}\right\}\end{aligned}\right\} \tag{25}$$

These equations (**23**) and (**25**) can be written in various different forms. They are interesting in showing in a direct-current circuit, features which usually are considered as characteristic of alternating currents, that is, of wave motion.

The first term of (**23**) or (**25**) is the out-flowing or main current or voltage, respectively; the second term is the reflected one.

At the end of the circuit with distributed constants, reflection occurs at the resistance r_0.

If $r_0 > \sqrt{\frac{r}{g}}$, the coefficient of the second term is positive, and partial reflection of current occurs, while the return voltage adds itself to the incoming voltage.

If $r_0 < \sqrt{\frac{r}{g}}$, reflection of voltage occurs, while the return current adds itself to the incoming current.

If $r_0 = \sqrt{\frac{r}{g}}$, the second term vanishes, and the equations (**25**) become those of (**19**), of an infinitely long conductor. That is:

A resistance r_0, equal to the effective resistance (surge impedance) $\sqrt{\frac{r}{g}}$ of a direct-current circuit of distributed constants, passes current and voltage without reflection. A higher resistance r_0 partially reflects the voltage—completely so for $r_0 = \infty$, or open circuit. A lower resistance r_0 partially reflects the current—completely so for $r_0 = 0$, or short circuit.

$\sqrt{\frac{r}{g}}$ thus takes in direct-current circuits the same position as the surge impedance in alternating-current or transient circuits.

D. Alternating-Current Circuits with Distributed Constants

$$b = \pm j q$$

by equation (**7**), a then becomes a general number: $\pm (h \pm j k)$, and the corresponding values of b and a exist:

$$\begin{aligned} b &= + j q, & a &= + h - j k \\ & - j q & & + h + j k \\ & - j q & & - h - j k \\ & + j q & & - h + j k \end{aligned}$$

Substituting these in equation (**4**), and substituting for the exponentials with imaginary exponent the trigonometric expression, gives

$$i = \epsilon^{-hl} \{B_1 \cos (kl - qt) + B_2 \sin (k l - qt)\} \\ + \epsilon^{+hl} \{B_3 \cos (kl + qt) + B_4 \sin (k l + q t)\} \quad \textbf{(26)}$$

where

$$\begin{aligned} B_1 &= A_1 + A_2 & B_3 &= A_3 + A_4 \\ B_2 &= j(A_1 - A_2) & B_4 &= j(A_3 - A_4) \end{aligned}$$

Resolving now the trigonometric expression of (**26**) into expressions of single angles, and eliminating the function of time by the introduction of the vector notation,

$$B_1 \cos qt - B_2 \sin qt = B_1 - j B_2 = \dot{A}_1.$$

$$B_2 \cos qt + B_1 \sin qt = B_2 + j B_1 = j \dot{A}_1.$$

$$B_3 \cos qt + B_4 \sin qt = B_3 + j B_4 = - \dot{A}_2.$$

$$B_4 \cos qt - B_3 \sin qt = B_4 - j B_3 = j \dot{A}_2.$$

gives as the expression of the current,

$$\dot{I} = \dot{A}_1 \epsilon^{-kl} (\cos kl + j \sin k l) - \dot{A}_2 \epsilon^{+kl} (\cos kl - j \sin kl) \quad \textbf{(27)}$$

and in the same manner, starting with equation (**5**),

$$\dot{E} = \sqrt{\frac{Z}{Y}} \{\dot{A}_1 \epsilon^{-kl} (\cos kl + j \sin kl) + \dot{A}_2 \epsilon^{+kl} (\cos kl - j \sin kl)\} \quad \textbf{(28)}$$

where

$$\begin{aligned} Z &= r + j q L \\ Y &= g + j q C \\ q &= 2 \pi f \end{aligned} \quad \textbf{(29)}$$

These are the usual and well known equations of the alternating-current transmission line in symbolic expressions.

II. IMPULSE CURRENTS

A. General

Impulse currents are characterized by the condition, that the time exponent b in equations (**4**) and (**5**) is real.

By equation (**7**), to every value of b correspond two values of a, equal but of opposite sign:

$$\pm a'$$

By the same equation, to every value of a correspond two values of b:

$$b = u \pm s \quad \textbf{(30)}$$

where

$$s = \sqrt{m^2 + \frac{a^2}{L C}} \quad \textbf{(31)}$$

is the *energy transfer constant,*

$$u = \frac{1}{2} \left\{ \frac{r}{L} + \frac{g}{C} \right\} \quad \textbf{(32)}$$

is the *energy dissipation constant,* and

$$m = \frac{1}{2} \left\{ \frac{r}{L} - \frac{g}{C} \right\} \quad \textbf{(33)}$$

is the *distortion constant* of the circuit.

As b must be positive, it must be, by (**30**)

$$s^2 \leqq u^2 \tag{34}$$

Since u and b are real, by (**30**), s must be real, thus by (**31**), $m^2 + \frac{a^2}{L\,C}$ must be real and positive.

As m^2 is real, $\frac{a^2}{L\,C}$ must be real, and must either be positive, or, if negative, $-\frac{a^2}{L\,C}$ must be less than m^2.

a thus must be either real, or imaginary, but it can not be complex imaginary.

This gives two classes of impulse currents:

Non-periodic impulse currents: a real, a^2 positive.

Periodic impulse currents: a imaginary, a^2 negative, and $-a^2 \leqq L\,C\,m^2$

The terms "periodic" and "non-periodic" here refer to the distribution in space, but not in time, since as function of time the impulse currents are always non-periodic.

The relations between the constants thus are:

Non-periodic impulse currents:

$$\begin{aligned} a^2 &= \text{positive} \\ a &= \pm h \\ s &= \sqrt{m^2 + \frac{h^2}{L\,C}} \\ h &= \sqrt{L\,C\,(s^2 - m^2)} \\ u^2 &\geqq s^2 \geqq m^2 \end{aligned} \tag{35}$$

and corresponding values of a and b are:

$$\begin{array}{cc} a: & b: \\ +h & u - s \\ -h & u - s \\ -h & u + s \\ +h & u + s \end{array} \tag{36}$$

Periodic impulse currents:

$$
\begin{aligned}
a^2 &= \text{negative} \\
a &= \pm j\, k \\
s &= \sqrt{m^2 - \frac{k^2}{L\, C}} \\
k &= \sqrt{L\, C\, (m^2 - s^2)} \qquad (37) \\
s^2 &\leqq m^2 \\
k^2 &\leqq m^2\, L\, C
\end{aligned}
$$

and corresponding values of a and b are:

$$
\begin{array}{ll}
a: & b: \\
+ jk & u - s \\
- jk & u - s \\
+ jk & u + s \\
- jk & u + s
\end{array} \qquad (38)
$$

B. Non-Periodic Impulse Currents

Substituting (**35**) and (**36**) in (**4**) and (**5**), and rearranging, gives:

$$
i = \epsilon^{-ut} \left\{ A_1\, \epsilon^{-hl+st} + A_2\, \epsilon^{+hl+st} + A_3\, \epsilon^{+hl-st} + A_4\, \epsilon^{-hl-st} \right\}
$$

$$
e = \sqrt{\frac{L}{C}}\, \epsilon^{-ut} \left\{ c\, A_1\, \epsilon^{-hl+st} - c\, A_2\, \epsilon^{+hl+st} + \frac{1}{c}\, A_3\, \epsilon^{+hl-st} - \frac{1}{c}\, A_4\, \epsilon^{-hl-st} \right\} \qquad (39)
$$

where

$$
c = \sqrt{\frac{s+m}{s-m}} \qquad (40)
$$

These equations (**39**) can be simplified by shifting the zero points of time and distance, by the substitution:

$$
\begin{aligned}
A_1 &= D_1\, \epsilon^{+hl_1 - st_1} \\
A_2 &= D_2\, \epsilon^{-hl_1 - st_1} \\
A_3 &= \pm\, D_1\, \epsilon^{-hl_1 + st_1} \qquad (41) \\
A_4 &= \pm\, D_2\, \epsilon^{+hl_1 + st_1}
\end{aligned}
$$

$$
c = \epsilon^{+st_0} \qquad (42)
$$

Hence

$$t_0 = \frac{\log c}{s} = \frac{1}{2s} \log \frac{s+m}{s-m} \tag{43}$$

and writing $\quad t$ for $t - t_1 + t_0$

and $\quad l$ for $l - l_1$

they then assume the form:

$$\begin{aligned} i &= \epsilon^{-ut} \{D_1 [\epsilon^{-hl+s(t-t_0)} \pm \epsilon^{+hl-s(t-t_0)}] \\ &\qquad - D_2 [\epsilon^{+hl+s(t-t_0)} \pm \epsilon^{-hl-s(t-t_0)}]\} \\ e &= \sqrt{\frac{L}{C}}\, \epsilon^{-ut} \{D_1 [\epsilon^{-hl+st} \pm \epsilon^{+hl-st}] \\ &\qquad + D_2 [\epsilon^{+hl+st} \pm \epsilon^{-hl-st}]\} \end{aligned} \tag{44}$$

or, expressed in hyperbolic functions:

$$\begin{aligned} i &= \epsilon^{-ut} \{B_1 \cosh [hl - st(t - t_0)] - B_2 \cosh [hl + s(t - t_0)]\} \\ e &= \sqrt{\frac{L}{C}}\, \epsilon^{-ut} \{B_1 \cosh [hl - st] + B_2 \cosh (hl + st]\} \end{aligned} \tag{45}$$

or the corresponding sinh functions, in case of the minus sign in equation (**44**).

The impulse thus is the combination of two single impulses of the form

$$\epsilon^{-ut} (\epsilon^{-hl+st} \pm \epsilon^{+hl-st})$$

which move in opposite direction, the D_1 impulse towards rising l: $\frac{dl}{dt} > 0$, and the D_2 impulse towards decreasing l: $\frac{dl}{dt} < 0$.

The voltage impulse differs from the current impulse by the factor $\sqrt{\frac{L}{C}}$ (the "surge impedance"), and by a *time displacement* t_0. That is, in the general impulse, voltage e and the current i are displaced in time.

t_0 thus may be called the time displacement, or time lag of the current impulse behind the voltage impulse.

t_0 is positive, that is, the current *lags* behind the voltage impulse, if in equation (**43**) the log is positive, that is, m is positive, or: $\frac{r}{L} > \frac{g}{C}$, that is, the resistance-inductance term preponderates.

Inversely, t_0 is negative, and the current *leads*, or the voltage impulse lags behind the current impulse, if m is negative, that is, $\frac{r}{L} < \frac{g}{C}$, or the capacity term preponderates.

If $g = 0$, that is, no shunted conductances, the current impulse always lags behind the voltage impulse.

If $m = 0$, that is, $\frac{r}{L} = \frac{g}{C}$, or $\frac{r}{g} = \frac{L}{C}$, $t_0 = 0$, that is, the voltage impulse and the current impulse are in phase with each other, that is, there is no time displacement, and current and voltage impulses have at any time or at any space the same shape; *distortionless circuit.* m therefore is called the *distortion constant* of the circuit.

In the individual impulse

$$\epsilon^{-ut}(\epsilon^{-hl+st} \pm \epsilon^{+hl-st}) = \epsilon^{-hl}\,\epsilon^{-(u-s)t} \pm \epsilon^{+hl}\epsilon^{-(u+s)t} \tag{46}$$

the term ϵ^{-ut} is the attenuation of the impulse by the energy dissipation in the circuit, that is, represents the rate at which the impulse would die out by its energy dissipation.

The first term: $\epsilon^{-(u-s)t}$, dies out at a slower rate than given by the energy dissipation, that is, in this term, at any point l, energy is supplied, is left behind by the passing impulse, and as the result, this term decreases with increasing distance l, by the factor ϵ^{-hl}; inversely, the second term, $\epsilon^{-(u+s)t}$, dies out more rapidly with the time, than corresponds to the energy losses, that is, at any point l, this term abstracts energy and shifts it along the circuit, and thereby gives an increase of energy in the direction of propagation, by ϵ^{+hl}. In other words, of the two terms of the impulse, the one drops energy while moving along the line, and the other picks it up and carries it along.

The terms $\epsilon^{\mp st}$ thus represent the dropping and picking up of energy with the time, the terms $\epsilon^{\pm hl}$ the dropping and picking up of energy in space along the line. In distinction to u, which

may be called the *energy dissipation constant*, s (and its corresponding h) thus may be called the *energy transfer constant* of the impulse. The higher s is, the greater then is the rate of energy transfer, that is, the steeper the wave front, and s thus may also be called the *wave front constant* of the impulse.

Substituting in equations (**44**), $l = 0$, gives the equation of the impulse in a circuit with massed constants:

$$i = A\,\epsilon^{-ut}\,(\epsilon^{+st} \pm \epsilon^{-st})$$

$$e = B\sqrt{\frac{L}{C}}\,\epsilon^{-ut}\,(\epsilon^{+s(t-t_0)} \pm \epsilon^{-s(t-t_0)})$$

where

$$A = D_1 - D_2$$

$$B = D_1 + D_2.$$

Substituting in equation (**39**),

$$\begin{aligned} A_1 &= \pm B\,\epsilon^{+hl_1 - st_1 + x} \\ A_2 &= \pm B\,\epsilon^{-hl_1 - st_1 - x} \\ A_3 &= \pm B\,\epsilon^{-hl_1 + st_1 + x} \\ A_4 &= \pm B\,\epsilon^{+hl_1 + st_1 - x} \end{aligned} \qquad (47)$$

$$c = \epsilon^{+st_0} \qquad (42)$$

and writing

$$t \text{ for } t - t_1 + t_0 + \frac{x}{s}$$

$$l \text{ for } l - l_1$$

and rearranging, gives

$$\begin{aligned} i &= B\,\epsilon^{-ut}\{\epsilon^{-hl}[\epsilon^{+s(t-t_0)} \pm \epsilon^{-s(t-t_0)}] \pm \epsilon^{+hl}[\epsilon^{+s(t-t_0-t')} \\ &\qquad \pm \epsilon^{-s(t-t_0-t')}]\} \\ e &= B\sqrt{\frac{L}{C}}\,\epsilon^{-ut}\{\epsilon^{-hl}[\epsilon^{+st} \pm \epsilon^{-st}] \pm \epsilon^{+hl}[\epsilon^{+s(t-t')} \\ &\qquad \pm \epsilon^{-s(t-t')}]\} \end{aligned} \qquad (48)$$

where

$$t' = \frac{2x}{s} \qquad (49)$$

writing

$$t \text{ for } t - t_1 + t'$$

$$l \text{ for } l - l_1 + \frac{x}{h}$$

the substitution of (**47**) and (**42**), gives, after rearranging,

$$i = B \epsilon^{-ut} \{\epsilon^{-s(t-t_0)} [\epsilon^{+hl} \pm \epsilon^{-hl}] \pm \epsilon^{+s(t-t_0)} [\epsilon^{+h(l-l')} \pm \epsilon^{-h(l-l')}]\}$$

$$e = B \sqrt{\frac{L}{C}} \epsilon^{-ut} \{\epsilon^{-st} [\epsilon^{+hl} \pm \epsilon^{-hl}] \pm \epsilon^{+st} [\epsilon^{+h(l-l')} \pm \epsilon^{-h(l-l')}]\} \tag{50}$$

where

$$l' = \frac{2x}{h} \tag{51}$$

Equations (**48**) may be interpreted as showing two impulses, the main impulse, and the reflected impulse. The main impulse, with ϵ^{-hl}, decreases with increasing l, that is, progresses towards rising l. The reflected impulse, with ϵ^{+hl}, starts at the time t' after the start of the main impulse, and decreases with decreasing l, that is, progresses towards decreasing l.

The two current impulses lag behind their voltage impulse by time t_0.

Equation (**50**) shows the two component impulses, the first one dropping energy along its path, and thus decreasing with the time at a greater rate than corresponds to the energy dissipation, and the second one, displaced in position from the first one by distance l^1, picking up the energy dropped by the first one.

The current again lags behind the voltage by time t_0.

The distance displacement l^1 of the component impulse in (**50**) is related to the time displacement t' of the two component impulses in (**48**) by (**49**) and (**51**):

$$\frac{l'}{t'} = \frac{s}{h}$$

that is, l' is the distance traveled by the impulse during time t'.

In hyperbolic functions, equations (**50**) may be written:

$$i = B\,\epsilon^{-ut}\left\{\epsilon^{-s(t-t_0)}\cosh hl \pm \epsilon^{+s(t-t_0)}\cosh h\,(l-l')\right\}$$

$$e = B\sqrt{\frac{L}{C}}\,\epsilon^{-ut}\left\{\epsilon^{-st}\sinh h\,l \pm \epsilon^{+st}\sinh h\,(l-l')\right\} \qquad (\mathbf{52})$$

C. Periodic Impulse Currents

Substituting (**37**) and (**38**) in (**4**) and (**5**), separating the imaginary exponentials from the real ones, substituting the trigonometric expressions for the former, and rearranging, gives

$$i = \epsilon^{-ut}\left\{\epsilon^{-st}[D_1\cos kl - D_2\sin kl] + \epsilon^{-st}[D_3\cos kl - D_4\sin kl]\right\}$$

$$e = \sqrt{\frac{L}{C}}\,\epsilon^{-ut}\left\{c\,\epsilon^{+st}[D_2\cos kl + D_1\sin kl] + \frac{1}{c}\,\epsilon^{-st}[D_4\cos kl + D_3\sin kl]\right\} \qquad (\mathbf{53})$$

where

$$c = \sqrt{\frac{m+s}{m-s}} \qquad (\mathbf{54})$$

Substituting:

$$\begin{aligned} D_1 &= \pm B\,\epsilon^{-st_1}\cos kl_1 \\ D_2 &= \pm B\,\epsilon^{-st_1}\sin kl_1 \\ D_3 &= \pm B\,\epsilon^{+st_1}\cos k\,(l_1 - l_0) \\ D_4 &= \pm B\,\epsilon^{+st_1}\sin k\,(l_1 - l_0) \end{aligned} \qquad (\mathbf{55})$$

$$c = \epsilon^{+st_0} \qquad (\mathbf{56})$$

Thus,

$$t_0 = \frac{\log c}{s} = \frac{1}{2s}\log\frac{m+s}{m-s} \qquad (\mathbf{57})$$

and writing

$$t \text{ for } t - t_1 + t_0$$
$$l \text{ for } l + l_0$$

gives

$$i = B\,\epsilon^{-ut}\left\{\epsilon^{+s(t-t_0)}\cos kl \pm \epsilon^{-s(t-t_0)}\cos k\,(l-l_0)\right\}$$

$$e = B\sqrt{\frac{L}{C}}\,\epsilon^{-ut}\left\{\epsilon^{+st}\sin kl \pm \epsilon^{-st}\sin k\,(l-l_0)\right\} \qquad (\mathbf{58})$$

Exchanging sin and cos in (**55**), also exchanges sin and cos in (**58**).

Equations (**58**) of the periodic impulse have the same form as equations (**52**) of the non-periodic impulse, except that the trigonometric functions of distance take in the periodic impulse the same position as the hyperbolic function in the non-periodic impulse.

Current and voltage are in quadrature with each other in their distribution in space, in either of the two components of the periodic impulse. That is, in each of the two components maximum current coincides with zero voltage, and inversely.

The two components of the periodic impulse differ in the phase of their space distribution by the distance l_0, the second component lagging behind the first component by the distance l_0.

In each of the two components of the periodic impulse, the current lags behind the voltage by the time t_0.

Current and voltage thus are in quadrature with each other in space, and displaced from each other in time, by the "*time* displacement" t_0.

t_0 is positive, that is, the current lags behind the voltage by time t_0, if m is positive, and t_0 is negative, that is, the current leads the voltage, if m is negative.

Since $m = 1/2\left(\frac{r}{L} - \frac{g}{C}\right)$ it follows:

The current lags behind the voltage, if $\frac{r}{L} > \frac{g}{C}$, that is, if the resistance-inductance effect preponderates.

The current leads the voltage if $\frac{g}{C} > \frac{r}{L}$, that is, if the capacity effect preponderates.

The voltage equals the current times the surge impedance $z = \sqrt{\frac{L}{C}}$, but is in quadrature with it in space, and the current is lagging by t_0 in time.

By the conditions of existence of the periodic impulse, s must numerically be smaller than m.

$$s = 0 \text{ gives}$$

$$\text{by } (\mathbf{57}): \quad s t_0 = 0.$$

$$\text{by } (\mathbf{37}): \quad k = m\sqrt{L\,C}$$

and by (58),

$$i = B\,\epsilon^{-ut}\,\{\cos k\,l' \pm \cos k\,(l' - l_0)\}$$

$$e = B\sqrt{\frac{L}{C}}\,\epsilon^{-ut'}\,\{\sin k\,l' \pm \sin k\,(l' - l_0)\}$$

Hence, current and voltage are in phase in time, but in quadrature in space.

$$s = m \text{ gives}$$

$$k = 0$$

hence, from (53),

$$i = \epsilon^{-ut}\,(D_1\,\epsilon^{+mt} + D_3\,\epsilon^{-mt})$$

$$e = \sqrt{\frac{L}{C}}\,\epsilon^{-ut}\,(D_2\,\epsilon^{+m\,(t+t_0)} + D_4\,\epsilon^{-m\,(t+t_0)})$$

hence, substituting for u and m,

$$i = D_1\,\epsilon^{-\frac{g}{C}t} + D_3\,\epsilon^{-\frac{r}{L}t}$$

$$e = \sqrt{\frac{L}{C}}\left\{D_2'\,\epsilon^{-\frac{g}{C}(t+t_0)} + D_4'\,\epsilon^{-\frac{r}{L}(t+t_0)}\right\}$$

where

$$D_2' = D_2\,\epsilon^{+ut_0}$$

$$D_4' = D_4\,\epsilon^{+ut_0}$$

In this impulse, the capacity terms and the inductance terms are separate, and current and voltage are uniform throughout the entire circuit.

The constants D or A or B are determined, as integration constants, by the terminal conditions of the problem.

For instance, if at the starting moment of the impulse, that is,

at time $t = 0$, the distribution of current and of voltage throughout the circuit are given, we have by (**53**), for $t = 0$,

$$i = \{(D_1 + D_3) \cos kl - (D_2 + D_4) \sin kl\}$$

$$e = \sqrt{\frac{L}{C}} \left\{ \left(c\, D_2 + \frac{D_4}{c}\right) \cos kl + \left(c\, D_1 + \frac{D_3}{c}\right) \sin kl \right\}$$

The development of the given distribution of current and voltage into a Fourier series thus gives in the coefficients of this series the equations determining the constants D_1, D_2, D_3, D_4.

The expressions for i and e, given in equations (**39**), (**44**), (**45**), (**48**), (**50**) and (**52**) for the non-periodic, and in equations (**53**) and (**58**) for the periodic impulse, obviously apply to a simple impulse only, and a general impulse is represented by the sums $\Sigma\, i$ and $\Sigma\, e$ of all the expressions i and e, whose integration constants satisfy the terminal conditions of the problem.

DISCUSSION ON "THE MEASUREMENT OF DIELECTRIC LOSSES WITH THE CATHODE RAY TUBE" (MINTON), DEER PARK, MD., JULY 2, 1915. (SEE PROCEEDINGS FOR JUNE, 1915.)

(Subject to final revision for the Transactions.)

H. W. Fisher and R. W. Atkinson: I believe the company with which the writers are associated was one of the first in this country to make extensive experiments relative to dielectric losses in cables and insulating materials.

After receiving valuable suggestions from the Bureau of Standards, special apparatus was designed for this work, which in connection with a vibration galvanometer was found to give very satisfactory results in determining dielectric losses, power factors, a-c. capacitance, etc. With this apparatus, varnished cambric manufactured by different companies was tested and power factors obtained at ordinary temperatures ranging between 4 and 20 per cent. A special apparatus was designed by means of which single thicknesses of insulating materials could be tested and also another apparatus in which the dielectric properties of insulating compounds could be determined. Later a Rowland dynamometer was adapted as a very sensitive wattmeter, for measuring energy losses at high voltages.

Experimental cables, made with varnished cambric of high dielectric loss, when subjected to excessive voltages, gradually became hotter and hotter until burn-outs occurred, whereas similar cables made with material of small dielectric loss and subjected to the same test, scarcely became warm.

Many different tests were made and the results carefully investigated in order to determine the best materials to use and the best methods of treatment of different dielectrics, etc. Some of the results of these tests have appeared in one or more papers presented by the authors at previous meetings of the A. I. E. E. A careful study of the results of all these experiments made on a great variety of materials manufactured or treated in different ways showed how dielectric losses can be reduced to a minimum, thereby insuring serviceable and efficient manufactured products.

Referring once more to the paper of the author, we find that the tests given were made on samples of varnished cloth and pressboard. As we have had no experience with the latter material, our comments will refer to tests of varnished cloth, dry paper as used in telephone cables, and saturated paper as used in electric light and power cables.

After carefully examining the results of the author's experiments on different samples of varnished cloth, we find that these are practically in agreement with tests made by us. The power factor of cables insulated with varnished cloth does not change appreciably with increase of voltage up to the operating voltage of the cable. As the voltages are increased above this point a slight increase in the power factor takes place, the rate of increase becoming greater as the voltage approaches the point of rupture.

We also find that the power factor increases with rise of

temperature in somewhat the same way as shown by the author in Fig. 12. It should be borne in mind that in the case of varnished cloth, lower power factors can be obtained by the application of high temperatures for a long time, but such a treatment if carried to excess injures the mechanical properties of the cloth, thereby making the cables more liable to injury from bending during the process of installation.

We have found that the capacitance of varnished cloth cables does not appreciably change with voltage or temperature up to the point where a marked change occurs in the power factor. By the use of the term capacitance we mean the capacitance as measured by a-c. method and not that as usually measured by the discharge deflection galvanometer method. The apparent capacitance as measured by the latter method increases very rapidly with rise of temperature.

In the case of dry core telephone cables the percentage of moisture in the paper may very much affect the insulation resistance, and the apparent electrostatic capacity, and the temperature coefficients of these. A statement of the amount of moisture contained is somewhat arbitrary, because further moisture can always be eliminated from dry paper in any condition, until complete charring is reached. Our results on this material are, in general, similar to those given in Figs. 26 and 27 of the paper, except that any increase in moisture produces some increase in capacitance and in power factor. However, as shown in these curves, the effect upon these properties is very slight for a small amount of moisture and the effect is much less at low temperatures than at high. One half of one per cent moisture in the paper of any cable does not increase the apparent capacitance much above that of the same cable where the amount of moisture has been eliminated as far as possible without charring the paper. As the percentage of moisture becomes greater, the apparent capacitance increases at a greater and greater rate at ordinary temperatures, and becomes excessive at high temperatures. The true capacitance also increases with increase of moisture and temperature, but at a much less rate. The effect of moisture as shown in our tests on dry paper is also similar to the data given in Fig. 27, except that the power factor at low temperatures is lower for dry paper and there is no dip in the curve. We have, however, found, in tests made on many compounds, that there is a temperature at which the power factor is a minimum.

In the case of saturated-paper-insulated cables we have found that the power factor and capacitance vary with voltage and temperature in much the same way as already shown in the case of varnished cloth, the principal difference being that the power factor of paper-insulated cables at low temperatures is very much less than that of varnished cloth. Of course, the materials used and the method of treatment, both in the case of varnished cloth and of paper, very much affect the absolute

value of the power factor, but without influencing the general characteristics just described. The general effect of moisture in saturated-paper-insulated cables is similar to that described by the author for treated pressboard.

We have found that dielectric loss in some few cases measured at low temperatures varies directly with frequency, whereas at high temperatures where the loss has been considerable, there is slight variation with frequency. These results were obtained from tests within the limits of 25 and 60 cycles.

The importance of dielectric loss lies in the fact that it produces heat and thus still further increases the temperature of the cables. This is most serious at high voltages, because for the same power factor, the energy loss is then so much greater. The Institute Standardization Rules take account of this by allowing different limiting temperatures for cables operating at different voltages.

A. S. McAllister: The author states that the loss varies with a power of the voltage ranging from 1.3 to 2.5. The loss should be expected to vary at some power of the voltage not less than 2. It is not improbable that the tests at higher voltages were made on materials physically different from those used in the tests at lower voltages, the change in the character of the material being brought about by the increased temperature. If as the temperature is increased the conductivity of the material decreases the loss will vary at a power of the voltage less than 2. If, however, the conductivity increases with increasing temperature, the loss will vary at a power of the voltage greater than 2. I should like to ask the author if the change in conductivity with change in temperature has any bearing on the cases reported by him.

John P. Minton: That point is explained in the paper.

W. I. Middleton and C. L. Dawes: Mr. Minton has, we believe, underrated the information obtainable from low-voltage d-c. measurements of the resistance and of the capacity of insulating materials. In connection with cables we have found in many cases that the insulation resistance drops materially after the insulation has been subjected to electrostatic stress, especially if the stress is carried near or to the breakdown point. We have found that the ability of the insulation to recover its initial resistance is a means of determining as to whether it has been permanently injured by over-stress or not. Certain high grades of insulation show no appreciable drop in insulation resistance after being subjected to high stress. These facts are borne out to a certain extent by Figs. 7 and 13 in the paper, where the total loss increases faster than the voltage squared. The hysteresis loss is of course included in the losses as shown in these figures.

We have further found that the d-c. capacity increases with stress and also if a high condition of stress is reached, the capacity may not return to its initial value. Similar results are shown by the author in Figs. 15 and 23 where the current increases

faster than the voltage and also in the statement of conclusion 2 by Mr. Minton. These effects have a very important bearing upon cable testing, for by the insulation and capacity measurements, too severe testing of the insulation can be detected.

In Tables I and II are given data illustrative of these effects.

TABLE I—WIRES SHOWING RESULTS OF STRESS.

MEGOHMS IN 1000 FT.

Test No.	Feet	Before voltage	2500 volts 1 min.	5000 volts 1min.	After 2 hr.	5000 volts 5 min.	After 2 hr.	
1	1562	14,500	14,500	7,500	11,500			
2	1547	22,000	22,000	16,000	18,000			
3	3150	7,500	7,500	6,000	7,000	5000	5000	
4	1740	15,000	15,000	6,500	10,000	750	2500	
5	2402	15,000	15,000	7,500	10,000	2500	3500	
							Break-down voltage	Megohms in 1000 ft. after repair, 4000 volts, one min.
6	3560	4,800				4620	13,000	4400
7	1425	3,500				3440	12,000	4470
8	2350	9,000				9015	15,000	8425
9	2750	7,660				7660	15,000	9150
10	2400	2,950				2740	7,500	2810

TABLE II—WIRES SHOWING RESULTS OF STRESS.

MICROFARADS PER 1000 FT.

Feet	Before voltage test	After 5000 volts for 1 min.
3150	0.126	0.130
2176	0.146	0.150
2470	0.130	0.134
2925	0.130	0.133
2775	0.120	0.124

In impregnated paper cables, high insulation resistance and high dielectric strength rarely occur simultaneously. A high insulation resistance may mean a low degree of impregnation and consequently low dielectric strength. This is due not only to insufficiency of insulating compound, but to the fact that the dry paper is more or less brittle and becomes injured mechanically with handling. An increase in the amount of impregnating material may reduce the insulation resistance but increase the dielectric strength of the cable. Thus it can be seen that considerable information is obtainable from low-voltage measurements.

As a matter of interest to ourselves we have measured insulation losses upon commercial lengths of cable by means of a portable wattmeter. The current coil was connected in the ground lead going to the sheath and the voltage was stepped down by means of a potential transformer. The inductance

of the potential coil of the instrument was made negligible by connecting a high non-inductive resistance in series with it. Although we did not know the phase angle of this particular potential transformer, the maximum error from this source, computed from the phase angles of similar transformers, did not exceed 5 per cent. We soon expect to be in a position to check these results by another method. Of course, this method would not be applicable to the small samples tested by Mr. Minton.

F. W. Peek, Jr.: Mr. Minton's paper shows clearly the great importance of thoroughly drying and removing occluded air from insulations before putting them into apparatus; the importance of operating at moderate temperature; and the necessity of keeping apparatus free from moisture. The chief use of loss measurements in practise is to check the condition of the insulation before it is put into use.

It may be of interest to compare the mechanism of loss in gaseous, liquid and solid insulations.*

In oil, and particularly in air, there is very little loss until local breakdown is reached. The loss in brush discharge or corona then increases directly as the square of the excess voltage above the critical voltage. With solid insulations, loss appears as soon as voltage is applied. The loss may be due to:

(1) The so-called dielectric hysteresis or lag of the flux behind the e. m. f. due to some molecular action.

(2) The loss due to conduction. Practically all solid insulations absorb moisture to a greater or less extent. The capillary tubes and microscopic interstices, etc., in the structure become filled with moisture and gases. In the non-homogeneous structure this makes a complicated arrangement of capacities and resistances in series and in multiple, as shown diagrammatically in Fig. 1.

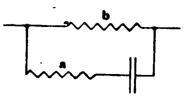

Fig. 1

The losses due to (1) should vary as the square of the voltage and approximately as the frequency.

$$p_1 \cong a_1 f e^2$$

The losses due to (2), Fig. 1, *a*, vary as the square of the voltage and approximately as the square of the frequency when the resistance is small and constant.
Thus

$$p_2 \cong a_2 f^2 e^2$$

The loss due to (2), Fig. 1, *b*, must vary as the square of the voltage, if the resistance remains constant, but is independent of the frequency.

$$p_3 = a_3 e^2$$

The total loss may then be made up of a number of components, thus:

$$p = p_1 + p_2 + p_3 = a_1 e^2 f + a_2 e^2 f^2 + a_3 e^2$$

*For more extensive data, etc., see Chap. VII, "Dielectric Phenomena in High-Voltage Engineering".

In poor insulation, or in insulation containing moisture, the loss may increase at a greater rate than the square of the voltage, as the resistance will decrease with increasing voltage.

In homogeneous insulations in good condition the last two terms are small and the expression for loss becomes

$$p = a\, e^2 f$$

and for certain insulations

$$p = a\, e^2 (f + c)$$

I believe that the deviations from the square law in Mr. Minton's paper are due to the conditions of the insulation. From examination of a considerable number of experimental data obtained by myself and others I have found that

$$p = a\, e^2 f$$

is generally followed, or, putting this in the gradient, g kv./mm., in place of e,

$$p = b\, g^2 f\, 10^{-6} \text{ watts per cu. cm.}$$

At 25 deg. cent. b is

2 to 15 for *oiled pressboard*—depending upon the quality or kind.
5 for *glass*.
7 to 10 for *varnished cambric*.

The values for *varnished cambric* were obtained for 60 cycles and 40,000 to 100,000 cycles. The values at the high frequencies were calculated from measurements made by Mr. Alexanderson.* These values follow very closely the square law.

The loss and, therefore, b, increases approximately with increasing temperature in the form

$$b = K\, t^n$$

where t is the absolute temperature in deg. cent.

For varnished cambric

$$b \simeq 1.2\, t^{10}\, 10^{-26}$$

or

$$p = 1.2\, g^2\, t^{10}\, 10^{-32} \text{ watts/cu. cm.}$$

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*Proceedings Radio Engineers, June, 1914.

"Dielectric Phenomena in High-Voltage Engineering", pages 185-187.

In some cases for insulations like varnished cambric I have noted that the equation sometimes takes the form

$$p = b\, g^2\, (f + c)$$

Charles L. Fortescue: Mr. Minton's paper is an example of the tendency to consider the problem of insulation in a scientific spirit. It is only in recent years that it has dawned on the minds of engineers that the problem of insulation is a subject that is capable of scientific treatment, and that good results will be obtained by considering it in this spirit. I may say that Dr. Ryan mentioned today an example of applying a simple principle of insulation to the problem of insulating apparatus for high-voltage testing, and he informed me that he had a great deal of trouble before applying this principle, but that after he had applied it he had no further trouble. It is necessary, however, in order to take full advantage of insulating materials, to determine their dielectric properties, and this is what Mr. Minton is showing us how to do. There are other methods of measuring the losses in insulation that are equally as good as far as commercial results go, but the advantage of this particular method seems to me to lie in the fact that it presents us with a graphic record of the test in the form of a Lissajous figure which may be an ellipse or something else. It occurred to me that we could obtain the analysis of current and e. m. f. from the Lissajous figure by applying a method similar to those which Mr. Chubb has brought out in some articles recently in the electrical journals, and an actual analysis of the operation of the dielectric could then be obtained.

By the method outlined in the paper we are enabled to determine whether any changes take place in the dielectric properties of the material during the cycle, which is a very important point. On account of its lack of inertia, the cyclograph may be used to determine the action of dielectric materials at very high frequencies, which, in connection with the effect of distorted waves on insulation, is a subject which has been given but very little consideration. It is very interesting to note that the dielectric losses may be expressed in terms of moisture and temperature by a very simple equation.

Mr. McAllister brought up the point that in his opinion the dielectric loss should be proportional to the square of the voltage. I do not think there is any reason for this assumption. The dielectric loss will not depend upon resistance in the true sense. When we talk of the a-c. resistance in the dielectric, we are simply using an expression based on the voltage component in phase with the current, and the actual loss may consist of a molecular loss which is due, one might say, to the polarization or displacement in the molecule itself, that is, to a change in the configuration of the electrons, but there is no reason to suppose that the loss due to any change in configuration is directly proportional to the square of the voltage.

W. C. Arsem: The subject of dielectric loss is assuming more importance as engineers are beginning to recognize its bearing on the quality of insulating materials. It is now realized that many failures of insulation are due to the cumulative effects of dielectric loss. If insulation be used under conditions such that the rate of dielectric loss, as heat, is greater than the rate of dissipation of heat by conduction and radiation, the temperature will rise. But the dielectric loss increases with rise of temperature, so that the insulation keeps getting hotter until it is melted, charred or punctured.

Mr. Minton is to be congratulated upon having perfected an apparatus by which a full set of measurements may be made in a short time. I hope full advantage will be taken of this apparatus and method to secure some accurate data on dielectric losses in pure and easily reproducible materials, such as mica, glass and oils at different frequencies, voltages and temperatures, and also different thicknesses of insulation. Such data would help to establish some theory of dielectric loss which would correlate all known phenomena and facilitate the improvement of insulating materials.

The theories that have been proposed to account for the properties of imperfect dielectrics fall into three general classes: First, the inhomogeneity theory of Maxwell, according to which an imperfect dielectric is assumed to be made up of portions having different dielectric constants and specific resistances. Second, the hysteresis theory which is based on the view that the dielectric displacement is not determined by the instantaneous value of the applied potential, but depends upon the previous history of the dielectric. The behavior of an imperfect dielectric in an electric field is not exactly analogous to that of iron in a magnetic field, for in a dielectric the final value of the displacement remains proportional to the potential, except that there is a time-lag. The loss per cycle in a dielectric, moreover, depends on the length of the cycle. A theory of viscous hysteresis has been developed by Pellat, in France, and von Schweidler, in Austria, which has been applied with some success in special cases.

The third theory advanced is the ionic theory. It assumes that in a *perfect* dielectric there is no conductivity in the ordinary sense, but only a practically instantaneous displacement of one or more electrons in each molecule when a potential difference is applied. In an *imperfect* dielectric, however, there are also ions of molecular dimensions resulting from the dissociation of the dielectric itself or impurities. These ions are responsible for residual charges, dielectric losses and the apparent variation of the dielectric constant with frequency.

The ionic theory is rapidly gaining favor, and to my mind is the most likely to prove correct.

In reference to Mr. Peek's remarks, just before his closing, it might be supposed from what he said, that it had been established that the loss depends upon the frequency and is in exact

proportion to it, but I do not believe that any results have been obtained yet which prove it conclusively. In fact, some data which have been obtained very recently in research work show that the relation is not linear. The ionic theory would indicate quite a different relation.

H. J. Ryan: The cathode ray tube has two familiar traits that are virtually its own: (1) Tracing cyclograms that furnish wave forms, cyclic energies, and power factors. (2) Condensers are employed exclusively for the voltage and current controls. In most work these control condensers are comparatively inexpensive and free of frequency and resistance errors. The tubes may, therefore, be used for indicating values at high voltages and sustained high frequencies, or at the highest frequencies in steadily recurring transients. By these two traits the cyclograph offers special advantages for the measurement of small powers applied at high voltages over the widest range of frequency. It has been found quite feasible and convenient to use the cyclograph without changing any of its adjustments to measure the voltage, current and power factor employed in corona formation about the same conductor at 60 and again at 180,000 cycles.

When we began to use high-frequency sources for experimental work and study, in our laboratory, we were distressed to find that it was difficult to provide insulating supports for the main electrodes carrying voltages of 50,000 and more. The conductors, a half inch in diameter and more, delivering such voltages, when supported on glass rods, glass or porcelain insulators or insulators of the usual refractory materials that might be employed, would cause such insulators to crack and fall to pieces. For the time being, cotton threads were the only enduring insulators and these conductors were thereby supported. That, of course, was very unsatisfactory. Then it occurred to us that the Fortescue-Farnsworth principle brought out beautifully in their paper and a demonstration of which I had witnessed in Mr. Fortescue's laboratory with high voltages at 60 cycles, was even more available at these higher cycles. By this principle, we eliminated the atmosphere that causes over-stresses, substituting all such atmosphere with solid dielectric. By the use of this principle every source of trouble in supporting conductors carrying high voltages at sustained high frequency completely disappeared. There should be no great difficulty in providing insulators for delivering, in so far as there will be occasion to deliver, the higher voltages at the higher frequencies.

R. P. Jackson (by letter): Mr. Minton's paper verifies similar data obtained in an entirely different way. Fig. 21 gives curves of power factor of oil-treated pressboard at different temperatures and voltages. The rise of power factor with temperature is perfectly natural, and is generally characteristic of most insulation. The falling of power factor with rise of voltage, however, is not characteristic of all insulation and is

a feature which was hard to believe when betrayed by our own investigations. For that reason, the data were taken over several times to verify the fact. The results remained the same, however, and the next problem is to find an explanation. In general, insulation having leakage has something of a coherer characteristic which causes apparent drop of resistance with rise of voltage, with consequent increase of losses more rapidly than the square of the voltage. Insulation having losses rising more rapidly than the square of the voltage, therefore, has a normal and readily explained loss and power factor curve. When the losses rise less rapidly than the square of the voltage and with a falling power factor with rise of voltage, there is evidently some polarizing element which is difficult to explain. Incidentally, this feature is highly desirable in insulation. We should like to know if any physical or chemical explanation has been offered, covering this feature.

H. W. Fisher: In the discussion by Professor Dawes and Doctor Middleton, the statement is made that in testing certain cables there was a great difference in the insulation resistance before and after the high-voltage test. I would like to ask Mr. Dawes what kind of insulation was used in the cables tested. We are meeting specifications which require that the insulation resistance before and after the voltage test shall differ by only a small amount. In wires insulated with certain kinds of material there might be a change in the insulation resistance before and after the voltage test, but in the case of saturated-paper-insulated cables, when tested at from two-and-a-half to three times the working pressure, the insulation resistance test made after the application of high voltage would be practically the same as that made before, provided the temperature of the cable has not changed during the application of high voltage. This may occur if the high-voltage test lasts for half an hour.

Chester L. Dawes and W. I. Middleton: In each of the instances cited the insulations were thirty per cent rubber compounds. The insulations that show such decided drops in resistance were low-voltage compounds not designed for the voltages to which they were subjected. Consequently, they were overstressed. On the other hand, the insulations which showed little or no drop in resistance were made of our high-tension compounds, designed to withstand high voltages without becoming overstressed. Both contain the same proportion of Para rubber (30 per cent), but the different characteristics are due entirely to the proportionate amounts of mineral ingredients added.

Clayton H. Sharp: It seems to me it is very important, for the general utilization of the details Mr. Minton has developed, to have certain means of exciting the tubes. Mr. Minton refers to a number of means in his paper. I think if we could hear a little more of the most practical way of doing it that it might be interesting.

C. W. Davis: The loss of energy in the dielectric is, as Mr. Minton has said, an exceedingly important matter and knowledge of it is necessary for the proper use of insulating materials. There are so many factors entering into the problem of insulation that this particular factor, *viz.*, energy loss, may, and sometimes does, receive undue weight. Enough is known of insulating materials at the present time to permit of the selection of insulating materials of low energy loss which are more or less suitable for any given purpose. To find the material that is exactly suitable is a different problem and the material which is exactly suitable under one set of conditions is anything but suitable under another. It is doubtful if there is any one material that will answer in the fullest degree all of the requirements, even in a relatively limited field of manufacture such as high-voltage cables. A cable that is laid in winter has very different demands upon the insulation than one laid in summer. A cable required for operation in very hot ducts will have to operate on a different portion of the temperature-energy loss curve than a cable laid under water. Material of relatively high energy loss may at times be the only logical selection where some other desirable physical characteristic becomes the controlling factor.

It is not obvious from reading the description of the improved form of Professor Ryan's power-factor indicator and the method of using it, why Mr. Minton should have preferred this method to that of the electrostatic wattmeter. To be sure, the latter is more or less troublesome to handle. However, it would appear to require much less space than the apparatus here described. An additional advantage of the electrometer is that it is direct reading. It is possible to build electrostatic instruments for measuring small losses in insulating materials which with air insulation at atmospheric pressure can be used in measurements up to 20,000 volts. With compressed air or gas as suggested by Rayner, and used by Tschernyschoff (*E.T.Z.* June 4, 1914, page 656), or with oil insulation, the measurements may be made at much greater voltages. Even low-voltage electrometers may be used with air condensers as potential dividers and while more troublesome are perhaps justifiable where more accurate results are desired. Besides, it would seem possible by superimposing an electric field upon the moving element, in the manner used by Fortescue* in the condenser terminal, to so largely reduce the stress at the edge of the needle as to overcome the difficulty from corona, though the consequent loss of pull on the needle would have to be compensated for by largely increased sensitivity.

Bridge methods have also been used with success up to 10,000 or 20,000 volts. Monash (*Annalen der Physik*, Vol. 22, 1907, page 905), succeeded in using a series bridge method successfully up to 12,000 volts. But the difficulties met with by Monash at high voltages are very considerably reduced in other bridge arrangements.

In the laboratories of the company with which the writer is

* TRANS. A. I. E. E. 1913, Vol. XXXII, Part I, p. 893.

connected we have made use of bridge methods for examining insulating materials for a number of years past (TRANS. A. I. E. E., 1907, Vol. XXVI, Part II, page 997) and more recently have made use of the Rowland dynamometer up to 100,000 volts and the electrostatic wattmeter up to 20,000 volts for measurements of the same general type as described by Mr. Minton.

The peculiar behavior of insulating material such as that noted in Fig. 21 of Mr. Minton's paper has been noted by us with oil-impregnated paper in one or two instances. The falling off of power factor with increased stress, however, is much less marked than with the material here referred to. The decrease of power factor with increasing stress was, however, as in Fig. 21, more marked at high temperatures than at low temperatures. So exceptional were these results that we have felt inclined to suspend judgment as to their credibility until we received further evidence. Mr. Minton's confirmatory results are therefore of much interest to us.

John P. Minton: In regard to Messrs. Fisher and Atkinson's discussion, they have taken up a number of examples that I intended to give, but neglected to do so on account of the length of the paper and the amount of material I had to present. I am glad, however, that these things have been brought up in connection with this discussion. They refer to the amount of moisture that an insulator contains, and I believe say that the results are more or less arbitrary, depending on the actual moisture present. The moisture I have dealt with in the paper is free moisture and not combined. You can eliminate the combined moisture by heating to a sufficiently high temperature to cause charring effects. That part of the moisture I have not considered at all, simply the free moisture which exists in the insulation, and which was determined with sufficient accuracy as described in the paper. Messrs. Fisher and Atkinson also referred to some results they had at 30 and 60 cycles. Results I have taken from 30 to 420 cycles show some very interesting facts. Later I hope to be able to publish some of these results.

Mr. Dawes said that I apparently underestimated the importance of steady potential effects. These effects I have not gone into in the paper, because the a-c. phenomena are far in excess of any d-c. effects that I noticed. I do not wish anybody to think we have underestimated anything whatever, because my experience has taught me not to underestimate any phenomena until they have been subjected to test.

Mr. Peek referred to the mechanism of dielectric conduction, the effects of frequency, and breakdown voltage, etc. These effects I have gone into, but on account of the length of the paper I left them out, hoping some one else would bring them up. The results that I have, showing the influence of frequency, however, will bring out certain effects which Mr. Peek spoke of as to the combination of capacities and resistances, and will also bring out the effect to which Mr. Dawes referred.

Mr. Fortescue inquired about the deflection being directly proportional to the voltage for the current deflection. He speaks of it as a velocity deflection. That is what Mr. Ryan referred to in his first paper in 1911. What I have called the current condensers he called velocity condensers. The way that comes about is this. Referring to Fig. 2, herewith, the instantaneous voltage, e, applied to the system is $e = E \sin \omega t$. The instantaneous current passing through the current condensers is $i = I \sin (\omega t + \theta)$. Now

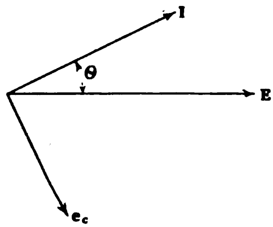


FIG. 2

$\frac{di}{dt} = I\omega \cos (\omega t + \theta)$, and the voltage, e_c, across the air current condensers is proportional to and in phase with this rate of change i. The deflection of the cathode ray stream is equal to some constant multiplied by e_c or by $\frac{di}{dt}$. For this reason Prof. Ryan has called velocity deflection and velocity condensers what I have called current deflection and current condensers.

He also refers to the square law as not necessarily something to be accepted. I have referred to that in my paper, and have taken it up quite fully, so that anybody should be able to appreciate the conditions under which we are working. It is not necessary, then, to explain that any more.

Mr. Arsem suggested the necessity of getting data on pure materials, with different thicknesses, and has also referred to the various theories that have been proposed. These theories I do not wish to consider at this time, because I do not wish to suggest any theory until I have a sufficient amount of data on which to base it. The results on pure materials are very necessary, but for the present the manufacturers and engineers desire results on actual materials used.

I do not think it is necessary to amplify or make any remarks in connection with Prof. Ryan's statements. I appreciate all of them even more than most people do.

Dr. Sharp has asked about the most practical way of exciting the tubes. The most practical way, so far as I know, is the method I have been using. This is a mechanical commutator which rectifies the peaks of the waves. I have used the commutator up to 30,000 volts—it is a small commutator made of fiber, with short brass segments at four equal points on the perimeter. That has not given me any trouble whatsoever, and it takes only a few seconds to start the tube. It is a simple and a convenient thing to use. I look favorably upon the kenotron developed by Dr. Dushman, but I have not had a

sufficient amount of experience with it to recommend it. There are other methods of exciting the tubes, but there are none of them which I consider as practicable as the mechanical commutator or the kenotron. Personally I prefer the mechanical commutator to all the others.

Several of the speakers have referred to the use of the dynamometer and the electrostatic wattmeter for measuring dielectric losses in insulation. It would seem that some of them cannot understand why the cyclograph method should have been preferred to these other two methods. For this reason some further remarks seem to be necessary. With regard to the ordinary electrostatic wattmeter, it may be stated that its use is out of the question for this work, for we wish to make measurements up to 200,000 volts or more. Furthermore, the method is not free from frequency errors, and reliable results cannot be obtained at the high frequencies. If oil insulation is used the greatest care must be exercised to prevent the oil from becoming unreliable through absorption of moisture or becoming mixed with other harmful foreign matter. It is difficult for me to feel certain of the accuracy of the results if any insulation other than air is used for work of this nature. With air one does not encounter frequency and resistance errors. With regard to the dynamometer, I may say this instrument has been in use in the Pittsfield laboratory for some time. I have made check measurements with the dynamometer and the cyclograph, and the agreement is satisfactory, being within a few per cent. It is necessary to make the check runs on test samples under exactly the same conditions. The dynamometer, however, is far from being satisfactory for low power factors, and cannot be used for measurements with anything but the ordinary frequencies, such as 60 cycles. It does not read direct and requires frequent calibration. It is no more convenient to operate than the cyclograph. If one wishes to make measurements up to very high voltages (200,000 to 500,000 volts) and at various frequencies up to say 10^6 cycles per second, he could hardly expect to make use of any apparatus other than the cyclograph. Since a study of insulation when subjected to high-frequency potentials is becoming of much importance, it is well to have apparatus such as the cyclograph to make use of.

Another important factor is the study of the effects in insulation produced by waves of various shapes, as well as the distortion in wave shape produced by the insulation itself. The graphic method of the cyclograph fulfills this requirement nicely. For these and other reasons I have preferred to use this apparatus in the work along the lines laid down in the present paper.

There has been no criticism of the results I have given. Everyone seems to be satisfied with the accuracy of them, and with the information which this method allows us to obtain.

DISCUSSION ON "ECONOMIC OPERATION OF ELECTRIC OVENS" (GUMAER), DEER PARK, MD., JULY 2, 1915. (SEE PROCEEDINGS FOR MAY, 1915.)

(Subject to final revision for the Transactions.)

Dwight F. Henderson: I think this paper has opened up a subject that will in the future be given a great deal of attention and study. The manufacturers spend a great deal of time in study and investigation and money in building efficient ovens, and then little attention is given to the operation of these ovens, ranges and other devices after they have been installed in the households. Our company in Spokane has been very active lately in pushing the sale of electric ranges and kindred devices. The greatest difficulty that our commercial men have found is in convincing the prospective users of this apparatus that the cost of operation is not going to be excessive. If this apparatus is used intelligently the cost in most cases is not excessive. We find that it closely approximates the cost of gas for a small family. I do not know how that would apply to a large family. I find, too, that the cost of heating water is the one great drawback with the electric ranges, if it is not done in some systematic manner. We have arranged a scheme for putting on a flat-rate water heater which has solved the problem as far as we are concerned, very nicely. We have developed a double snap switch interlocked so that when the range is turned on the water heater is off, and when the range is not in use the water heater is on. That gives an eighteen- or twenty-hour use of the water heater and will give continuous hot water when connected to the ordinary water tank.

Ralph W. Pope: I can see the coming of the scientific domestic engineer when, as prophesied by the author of the paper, we can have a definite degree of heat indicated at which food should be cooked, and also temperatures to which the oven should be heated, and any changes which may be necessary, may be brought about very readily. That appears to me a great advance.

There has been one serious drawback to the introduction of electrical apparatus in the kitchen, and that is the comparatively high initial price. It appears to me that that initial price might be made lower, when we consider that the revenue eventually is to be derived from the current consumed. Then, again, the higher cost of operation is not such a material objection. The cost is more than offset by convenience; frequently we pay more for cooking by gas than by coal, and still it is so advantageous, that the gas bill does not always trouble the kitchen. It is convenience we are looking for. As we all know, we have a great many conveniences which greatly increase the cost of living compared with our former more simple life.

S. N. Clarkson: The electric iron is quite a good revenue producer for the central station, and now that the manufacturers have given us satisfactory electric stoves, it opens up

another and a much larger field for central station service to replace its competitors. The cooking load is a very desirable one because a great deal can be added to existing systems without appreciably increasing the demand, due to the diversity factor of the cooking load.

The human element enters into the cooking so greatly that it is impossible to give any accurate cost data to fit all cases. It would seem that with proper care in the operation of the stoves, a rate of 3 cents per kw-hr. will about equal the cost with gas at 90 cents, and for rough computation, the current consumption of one kw-hr. per day per person is a fair average.

H. W. Flashman: I would ask the gentleman from Spokane if he will complete the discussion by telling us the rates of charge for gas and electricity. He stated he felt they broke even on electric cooking.

Dwight F. Henderson: Our rates for current are 8 cents for the first twenty kw-hr., 6 cents for the next ten kw-hr. and all in excess of that 3 cents per kw-hr. Our stoves are put on the same meter which supplies the general lighting of the house. We figure that about the first thirty kw-hr. will be used for lighting for an ordinary residence. That will leave most of the cooking to be done at the 3-cent rate, and our gas at Spokane is $1.40 per thousand feet, with certain discounts. I do not know just what the discounts are, but the convenience and other features of electric cooking offset the considerable difference in price between gas and the electric equipment. We have made approximately one hundred installations now, and our experience has been different from the report from St. Louis. The ranges for electric cooking, while they are not by any means perfected yet to the degree to which they will be, have met with general satisfaction. We have had only one or two cases where the installation was returned. The first cost has been a great handicap in the installation of electric cooking. We have to sell the average range laid down to us at from $65 to $90, and there is usually $15 to $20 expense incurred in wiring the house. We think that a large percentage of the people would be willing to stand the first cost if they were sure that the expense of operation would not be too high. Any simple rules that could be given to economize in the preparation of food would certainly be a great help.

H. L. Wallau: Mention was made of the diversity factor of the cooking load. I do not happen to recall the figures, but quite a few experiments were made some years ago in Cleveland, and these figures were presented to the Association of Edison Illuminating Companies in the report of the Committee on Electric Cooking about two or three years ago. I merely bring this point up, so that if any of the gentlemen present desire to get some data on that diversity, they can look the matter up in the report and will find quite complete data on that subject.

I will add further that in Cleveland we found that the cost of

cooking by electricity usually ranged from $1.50 to $2 a month per head, with current at 5 cents, and it was proportionately less than that with current at 3 cents. We had a 3-cent rate for what was known as the "four-hour load factor stove", that is, any stove the use of the connected load of which reached four hours a day, or more, received a 3-cent rate. If the use was less than four hours a day, the rate was 5 cents.

M. G. Lloyd: I am very glad to see going into our records some definite data on this subject. Most of the figures which have been available heretofore are of such an indefinite character, or were obtained under conditions not very precisely stated, that it is hard to tell just where we stand on the subject of electric cooking. I think it is of great value to us to have these definite experiments available. One thing that is worthy of note in this connection is this. I think there is a very definite tendency in this country to recognize the advantage of cooking at low temperatures, so that more of the nutritive value of the food is retained, that is recognized as a desirable element. These tests indicate that cooking under the best engineering conditions falls into line with that dietetic condition, that is to say, the most economical rate of temperature for cooking is the low temperature, at least in most of the cases specified. It is also to be remarked that by cooking at low temperature there is less loss in weight and consequently less food required for a given number of persons.

In regard to the suggestions made by the author as to what is required, it may not be known to every one that there are ranges on the market which meet some of these conditions, that is to say, the electric stove has already been combined in apparatus designed for the fireless cooker principle, and there are also ranges on the market which have been provided with automatic switches and time switches so the food can be put in the oven and the person in charge of the cooking go out of the house, and the cooking will go on for the proper time and at the proper temperature.

Discussion on "Phase Angle of Current Transformers" (Dawes), and "Calibration of Current Transformers by Means of Mutual Inductances" (Fortescue), Deer Park, Md., July 2, 1915. (See Proceedings for May and June, 1915.)

(Subject to final revision for the Transactions.)

George A. Campbell: This paper is of great value to us, and we shall adopt the method of measurement which Mr. Fortescue has developed with results which are, from both the theoretical and the commercial standpoint, so eminently satisfactory. The method belongs in the category of null conjugate branch methods, together with the Wheatstone bridge and the induction balance, which are well known to be the most accurate of all methods, as neither deflections nor test current magnitudes are involved. Without constructing any special apparatus, we have recently been trying the method for measurements of mutual impedance, the circuit being similar to Fig. 12 of the paper, but with the non-inductive resistance R included as in Fig. 1 of the paper, and with a telephone substituted for the synchronous contactor. At telephonic frequencies, accurate measurements are easily and quickly made. In the development of permanent apparatus for the method, it will presumably be advantageous to adopt the circuit idea of Fig. 13, as well as the toroidal type of coil which Mr. Fortescue has shown to be so well adapted for accurate commercial work.

For 25- and 60-cycle measurements, we would suggest the use of two dynamometers with their field coils energized, one in phase with the testing current and the other in time quadrature with the testing current. If the movable coils are then connected into a potential circuit in which resistance predominates, the deflections of the first and second dynamometers will be approximately proportional to the mutual resistance unbalance and the mutual reactance unbalance, respectively. These simultaneous quadrature indications would greatly shorten the time required to obtain a balance and make it possible to use this null method in the field where conditions are more or less fluctuating. The apparatus could also be used for the balance-deflection method by calibrating the dynamometers accurately enough for the small differences to be determined by the deflections.

Fig. 1 herewith will serve to illustrate this use of two dynamometers. Adjustable impedances Z_s and Z_m are indicated as a possible means for controlling the phase (and magnitude) of the currents in the resistance S and the fixed coil of dynamometer D_m. These two adjustments of the set itself may be made by the aid of the dynamometers of the set by connecting the terminals P_1, P_2 of the potential circuit to the terminals of the small non-inductive resistances R_s and R_m Once adjusted, this set is adapted for measuring the potential difference between any two points in any network, on the assumption, of course, that the apparatus will withstand the potentials and that the total capacity admittance between the current and potential circuits of the set is

small compared with the network admittance with which it is placed in series. Self- and mutual impedances are therefore measured without change in the set, and mutual impedances, as well as self-impedances, may have any phase angles. By inserting a mutual inductance M_1 at any point of a network, the current at that point may be measured. The wide use of the method thus seems to be best illustrated by Mr. Fortescue's Fig. 13.

Simultaneous quadrature indications might be obtained with two dynamometers excited from a small synchronously driven generator, the use of which is suggested in the paper. This would have certain advantages, but a single generator would not be suited for the entire range of power and telephone frequencies.

Simultaneous quadrature indications could be obtained with two contactors each provided with its d-c. vanometer. They could also be obtained by using two vibration galvanometers arranged to give Lissajous ellipses, connecting one in the current circuit and the other in the potential circuit and reflecting a

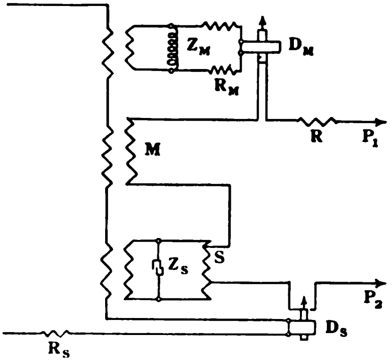


FIG. 1

single beam of light in sequence from both mirrors. Many other methods of securing simultaneous readings might be suggested, making use, if desired, of the synchronous stroboscope and Einthoven string galvanometer suggested by Mr. Fortescue.

As a uniform single-layer coil wound on a ring encircles the axis of symmetry of the ring with one turn, such a winding will have an external field, and it may have mutual inductance with a circuit which is not looped with the ring. The fewer the turns in the layer the greater the relative importance of this loop. This effect can be guarded against by using two layers wound in reverse directions around the axis, by doubling back the conductor in two or more strands outside of the single layer, or by beginning the winding with a single turn around the axis at the mean position of the winding. To prevent the possibility of this requirement being ignored when it might be of importance, it would be well to cover this point in referring to the well-known property of toroidal coils, even though this is in no way a matter

which affects the intrinsic accuracy of the mutual inductance method.

I believe that the theoretical correctness and the practical convenience, accuracy and flexibility of this method will lead to its extensive use.

L. W. Chubb: This apparatus which Mr. Fortescue has originated has been in use for some time, and I wish to call attention to one or two points that do not seem to be brought out very clearly.

The apparatus is used in the shop, not in the laboratory—it is not essentially a laboratory method. It is built as a unit and used in the transformer testing department by men who work more or less by rule of thumb. The apparatus has been in use for all kinds of different testing. Even in the different laboratories, when it is necessary to find the effective resistance of certain reactances or test mutual inductances, or make any other careful tests for research work, we find the men taking their problems to the shop instead of the shopmen taking their problems to the research department. The apparatus is always available and can be arranged to make very accurate tests in this way.

Clayton H. Sharp: There is no doubt that the importance of the measurement of the ratio and phase angle of current transformers is great enough to justify all the work in making the apparatus which Mr. Fortescue describes, if it were applicable to that work alone; but he has shown it can be used also for other very important kinds of work. It differs from apparatus in use elsewhere, in that mutual inductors are used instead of non-inductive shunts. It would seem that the mutual inductance method has advantages over the non-inductive shunt method, in that it can be applied to other fields of work. For the measurement of the current transformers alone, it would seem to be a question of which is more convenient to make and calibrate rather than anything else; that is to say, the decision as to which method is chosen is to be based on the matter of convenience and cost, rather than on any essential differences between the shunt and the mutual inductor method.

I would like to ask Mr. Fortescue if he considers that it is on the whole advisable to go to the trouble of making the inductors in a form such that their mutual inductance can be computed, rather than to make up something which has about the requisite value and then to determine what that value is by comparison with a standard. I am rather impressed by the large amount of apparatus which is shown in Fig. 7. This may not all be essential, but certainly a good deal less is required if the shunts are used.

Regarding the method of detecting the zero balance, Mr. Fortescue has used a synchronous reversing key and d-c. galvanometer. That method has some great advantages—it makes a shop method out of what would otherwise be a laboratory method. The vibration galvanometer has been mentioned in this

connection. We recently had some experience at the Electrical Testing Laboratories with the vibration galvanometer. The vibration galvanometer is made to vibrate, and it is very partial to vibrations. It does not care particularly whether they are electrical vibrations or mechanical vibrations, so that if the galvanometer is not on a foundation which is free from vibrations, it is likely to do anything. We found we could not use it without resorting to some elaborate system of anti-vibration supports. It is not a shop system.

Mr. Fortescue refers to the separately excited electrodynamometer. We have recently found on the market a little pointer electrodynamometer, which is very sensitive indeed, sufficiently sensitive for this work. Its field is excited with current at any desired phase-angle by using a phase-shifter constructed from a small induction motor. Hence the in-phase and the quadrature components of the secondary e. m. f. can be compensated separately. This also can be classed as a possible shop apparatus rather than as purely a laboratory apparatus. It gets rid of the trouble, if there is any, of synchronizing the motor, and also, what is of importance under the same conditions, of the noise made by the vibrating switch.

James R. Craighead: A few years ago it became necessary for us to select a method of testing current transformers for detail development in our laboratory. At that time the shunt method and the mutual inductance method were both under consideration. The determination to take up the shunt method was really based on two difficulties connected with the mutual inductance method, one of which Mr. Fortescue seems to have thoroughly eliminated. The two difficulties were, first, the large number of small contacts to be kept in practical working operation. That difficulty, according to Mr. Fortescue's statement and diagram, seems to be still left in the method. The second difficulty was the fact that our mutual inductances were easily affected by stray fields, external metal masses, etc., so that the results we obtained did not make it worth while to develop the method in opposition to the shunt method. Consequently, we have used the shunt method, but I feel that in eliminating what is really the chief difficulty of the mutual inductance method Mr. Fortescue has made a big step in advance and provided something which will undoubtedly be a satisfactory method of testing.

One question that always comes up in the comparison of methods of testing current transformers is—what will be the effect of varying wave form of the supply circuit in each method? Here, we get a distinct difference between the results obtained by the shunt method and by the mutual inductance method, because of the different effect which the harmonics have in the two cases. In the mutual inductance method the harmonics are present in the secondary of the mutual inductance, as the first differential of the corresponding harmonics of the current

wave, and consequently have a tendency to be exaggerated and to give a somewhat different effect in phase angle measurement from what is obtained by any direct comparison of r. m. s. values. In the shunt method the harmonics are present in the form of a drop across the shunt, which corresponds to the current wave, instead of the differential of that wave, and this tends to make its effect in any apparatus through which it is used proportional to the value that would be obtained by a comparison of the r. m. s. values instead of some other function. This is a slight advantage for the method, but one which is by no means conclusive, because errors in ratio and phase angle tests due to differences of wave form are so small. We have tried comparative tests on current transformers a great many times, using a rather exaggerated wave on one of the machines in our laboratory, as compared with a wave which is within about one per cent of a true sine, and the difference in ratio obtained by two different methods of test is limited to about 0.2 of one per cent in the extreme, for quite a wide variation of waves. The difference of phase angle is limited to between 5 and 10 min. in the same case. Test on the actual wave form on which the transformer is to be used is therefore usually unnecessary.

This method which has been presented is worthy of thorough consideration and comparison in any place where convenience and use in the shop are to be considered. The shunt method is also extremely simple and easy to use, but it involves the use of sensitive instruments to a higher degree than the mutual inductance method, and it also involves the use and preparation of shunts of large capacities, the difficulties of making which are pretty well understood, and whose construction up to a few thousand amperes is perfectly practicable.

Mr. Fortescue is using a commutator and a galvanometer as his means of test. This question has been discussed at several previous Institute meetings, and I will not go into that again. I suggest that the separately excited dynamometer with phase shifting excitation has proved satisfactory in other methods and should prove satisfactory here.

In regard to Mr. Dawes's paper on the phase angle of current transformers, there has been a need for a considerable while for some practical means of testing transformers under actual load conditions without the introduction of any secondary instrument. The method which he presents offers the very great advantage of allowing exactly that; that is, it is possible during the test of the transformer to use in the secondary not only the same kind of instrument, but exactly the same instrument and same circuit connections which will be used when the transformer is used for accurate testing. At the same time there are several elements which, except under the most careful supervision by thoroughly expert men, and with instruments in thoroughly good order, might militate against the success of the measurements.

There are several correction angles which must be considered in order to obtain accurate results. In the paper these correction angles are given so accurately and the results checked to such an excellent point, that it gives a little the appearance that the correction for these angles would always be easy, whereas I think it would not be. In the first place, we have the angle called alpha, which is the variation due to the inductance of ammeter and wattmeter coils. This is dependent on the instrument used and the resistance placed in circuit. It can be minimized by large resistance and small current, but that is not always easy to do, for the reason that it is frequently necessary to use currents up to the full limit of the transformer, and the supply circuit must necessarily be of considerable power in order to use it up to that point, without diminishing the series resistance to the point where the correction angle is considerable.

Then there is the angle theta, which is the angle between current and potential in the wattmeter circuits, caused by the inductance or capacity used in series with the wattmeter and voltmeter potential circuit. That angle has only a secondary effect on the result; that is, the result depends on the measurement of the actual values of watts read in two conditions, and the relation between those values depends on the power factor of the circuit. This is represented by the power factor of the potential circuit. Any failure or variation of this angle has only a small secondary effect on the final answer.

Then there is the angle called gamma in the paper, which is the angle between the primary current and V_1, due to the current drawn out of phase in the wattmeter and voltmeter potential circuit through the inductance or capacity. This is dependent on the amount of this current, the relations of the capacity, inductance and resistance, and the total amount of the primary current. It can be minimized by the use of large primary current and small currents in the potential circuit. These two things are sometimes antagonistic and render the measurements of the transformer of small ratio a little difficult, where the other error due to the angle alpha renders the measurements of the transformer of large capacity a little difficult.

Another thing, as to the measurements made on the instruments themselves and the resultant answer. In Mr. Dawes's paper, in the case he recited, the difference between the watts in the primary and watts in the secondary amounted to from two to four per cent of the reading. Now, unless the reading is carried well up on the scale of the instrument employed—requiring either a large current in that circuit, or an instrument of high impedance, both of which may be objectionable—that 3 or 4 per cent difference will be a difficult quantity to read to the accuracy that is desirable to obtain these angles correctly. In a phase angle of 28 min., such as is represented here, the variation corresponding to one minute would be perhaps one-fortieth of the difference of reading or about 0.1 of one per cent. That is a pretty close point to which to hold readings of that kind.

I am not attempting to object to the method in calling attention to these practical difficulties in the operation of it. The method appears a thoroughly practicable one, and one which can be carried out successfully, but it would require a most thorough and careful handling of the entire instrument situation in order to get results, so that if used in routine or in the shop, it would be attended with decided practical difficulties.

Clifford W. Bates: There is one point in regard to Mr. Dawes's paper about which I would like to remark. Assuming that the data are correct to the last significant figure, the magnitude of the errors is about 1 part in 500. The cosine of the apparent phase angle is calculated from these data (probably by the use of four-place logarithms) and the phase angle itself is found and expressed to single minutes, that is, to an accuracy of about 1 part in 3000, or about six times as accurately as the data from which it was obtained. It is to be expected that this result is correct to rather less than 1 part in 500, or to about 6 min. Then the different determinations of the transformer phase angle (which depends on the apparent phase angle) would be expected to show deviations of rather more than 6 min., but this is not the case, as the various values found are 29 min., 28 min., 24 min., 28 min., 30 min., 27 min., and 26 min., with an average of 27.5 min. and an average deviation of 1.5 min.

In view of the fact that a calculated result may be in error by as great a percentage as the least accurate linear factor, I would like to ask Mr. Dawes how he accounts for the rather surprising agreement.

In regard to the matter brought up by Mr. Robinson, I would like to remark about the magnitude of the error which may be introduced by the phase angle of a wattmeter. We are accustomed to read that the wattmeter may introduce a bad error into the determination of the power taken by an inductive circuit. I had occasion to investigate this error recently, and in the course of my investigation I had the phase angles of all the portable wattmeters available measured. These included six different types of dynamometer wattmeters made by several different manufacturers—some American and some foreign. I found that, in the case of the instrument whose error was greatest, the absolute error at zero power factor was very little more than the error of reading the scale. To take a concrete instance, consider a meter whose normal range is 500 watts, and use it to measure a load of 500 volt-amperes at 1 per cent power factor. The instrument reading, if correct, would be 5 watts. Using the constants of the worst instrument which I had available, the error due to phase angle would amount in this case to about 2 watts (2/5 of one division). If this is considered as a percentage error, the error is 40 per cent, but as an absolute error it is almost negligible. Nearly as much error would be made in the reading itself; so that I consider that the phase angle error of a wattmeter is practically negligible under all conditions. These remarks apply only to wattmeters used without transformers.

George A. Campbell: I am interested in dynamometers, and would ask Dr. Sharp the name of the pointer dynamometer to which he refers.

Clayton H. Sharp: It is an instrument made by Robert W. Paul. It is a new thing, and is remarkably sensitive. If you have to use a delicate electrodynamometer it puts it out of the shop class. If you use a pointer instrument, it puts it on a par with a synchronous vibrator and pointer galvanometer.

Chester L. Dawes: Referring first to the question of electrodynamometers, at Cambridge we are using a Sumpner a-c. electrodynamometer. It is of the suspension type and is quite sensitive, but at the same time it can be handled quite roughly as far as permanent injury is concerned. At present we are using it to measure very low electrostatic capacities. With 110 volts at 60 cycles per sec., I find that I am able to obtain a deflection of something like 50 cm. on a scale 120 cm. from the instrument, with 5/100,000 microfarad in circuit, and the sensitiveness can be still further increased. The one great advantage of the separately excited instrument as a detector is, of course, that it need not be tuned, and it gives plus and minus deflections.

I appreciate very much Mr. Craighead's having gone over this paper so much in detail and also having pointed out the advantages and the limitations of this method of phase angle determination. I have already anticipated most of these limitations. For instance, when I saw that the inductance of the current coils of the instruments was such an important factor in the phase angle measurement, I immediately turned to the method illustrated by Fig. 5. The angle θ is readily determined because its cosine is the ratio of the wattmeter reading to the volt-amperes. There is no possibility of it changing in the two cases, even with an iron core inductance, because the voltage across this inductance is the same in each of the two cases. The objection to using an inductance having a magnetic circuit entirely of iron is that a third harmonic might be introduced into the potential circuit current due to the changing permeability of the iron.

I agree with Mr. Bates's statement that the number of significant figures should not represent a higher degree of precision than that to which the measurements were made. I think that he has in mind, however, the case of commercial instruments, used in the ordinary manner to measure current, potential and power. Such instruments when calibrated may have a precision of about 1/5 of 1 per cent, corresponding roughly to three significant figures. In my particular case, however, the absolute measurement of current and voltage was not essential, for the ammeter and the voltmeter were used merely to keep the current and the voltage respectively at the same values in the two consecutive measurements. An error of 2 or even 4 per cent in the absolute values of their readings would introduce no appreciable errors into the phase angle measurement, but would, of course,

show an erroneous value of secondary current. I only need to make the adjustments such that the ammeter and the voltmeter pointers come to the same scale readings in the two measurements, and this can be done very accurately, especially when the pointers are in the proximity of a line. The wattmeter reading changes so slightly that its calibration is hardly necessary, but as an extra precaution, I checked the instrument at the points near which it was used. In view of the above facts, and also because I was able to make very fine adjustments of both the frequency and the voltage, I feel justified in carrying the result to four significant figures, one figure more than is justified under ordinary commercial conditions. But even then my results varied between the limits of 24 and 31 min., about 4 min. on each side of the actual value of the phase angle. This gives a precision of only 15 per cent in the angle itself. However, as a corrective term, the phase angle is added or subtracted from a much larger angle and the above 15 per cent maximum error then will affect the final results but slightly, in fact, to a much less extent than the errors of the instruments themselves.

If, as Mr. Bates contends, I am going beyond the precincts of precision in expressing my results to the nearest minute, my only alternative is, of course, to express them in tens of minutes, or to use only one significant figure. Even a casual observation indicates that the results are entitled to more significant figures than this.

There is another application of this method that is not mentioned in the paper. Oftentimes a standard transformer of known phase angle and having a ratio equal to that of the transformer under test is available. Under these conditions, the computations are very much simplified. The standard transformer is first inserted in circuit as in Fig. 1B, and readings W, E, and I are made. Let the phase angle of this transformer be β'.

Then from formula (**8**)

$$W = E\, I \cos \left[(\theta - \gamma) \pm \beta' \right]$$

As β' is known, $(\theta - \gamma)$ is readily determined.

The transformer to be tested is then substituted for the standard transformer, and readings W_2, E_2 and I_2 taken.

Then

$$W_2 = E_2 I_2 \cos \left[(\theta - \gamma) \pm \beta \right]$$

As $(\theta - \gamma)$ is now known, β is the only unknown quantity, and so may be easily determined.

Thus when a standard transformer is available, the corrective terms are eliminated and the computations are much simplified.

Charles L. Fortescue: I wish to agree with Dr. Campbell as to the advantages of using two instruments and also as to the

advantage of using properly excited electrodynamometers, which matter Dr. Sharp has also brought up.

I would also draw more particular attention to the failure to bring out the important point in this paper, which Dr. Campbell has drawn attention to. I state in the paper: " It is well known that a uniformly wound ring of uniform cross-section has no external magnetic force; it follows, therefore, that its mutual inductance with any circuit which does not encircle it must be zero." Dr. Campbell points out the fact that there is a revolution for each completely wound ring, round the axis of the ring and such a coil has an external magnetic field. Therefore, the statement in my paper should be qualified by adding, after the first sentence, "with the proper disposition of the finishing leads." This may be done in several ways, as Dr. Campbell has pointed out.

Dr. Sharp brings up the point—is it worth while to take so much pains to attempt to make the method absolute? I may say that there are two things involved here, one is to make it astatic, and the secondary consideration is to try to make it absolute—in making it astatic the possibility of making it also absolute came up, as I pointed out in the paper, and one essential thing, in order to make the apparatus astatic, is to have mechanical accuracy in the machining of the rings, which also suggested the possibility of making the method absolute. The importance of having the method absolute is really secondary to that of making the apparatus astatic.

I believe now, if the apparatus were to be redesigned, I would not take very much pains to try to calculate the mutual inductance. I would do as Dr. Sharp has suggested, compare it with a known standard, a very simple and easy thing to do.

Dr. Sharp called attention to another point which I expected to be brought up at this meeting, the amount of apparatus shown in Fig. 5. The trouble with most wiring diagrams is that they look more complicated than they really are. There is very little apparatus, considering the range of this device. Table III gives an idea of the range of this apparatus; it is capable of measuring the ratio of standard transformers over a range of ratios from 5 to 5 amperes to 4000 to 5 amperes. The apparatus is arranged to give at every ratio as near the maximum sensibility as possible. The arrangement shown in Fig. 5 was adopted because it is the standard method in use in the testing department of our factory for grouping the coils of testing transformers in series and multiple relations. The arrangement is in reality very simple, and the testing hands are accustomed to it, and it is always a good plan to maintain uniformity in switching connections in a testing department, as it reduces the possibilities of mistakes.

Another difficulty to which Dr. Sharp calls attention, is the question of synchronizing the motor driving the contactor. We have overcome that entirely by using a polyphase machine. One

drawback on a commercial testing floor in the use of the contact method is due to the fact that the person using this apparatus is not the only one on the circuit. Heavy loads may be taken off any particular phase, so that it is frequently necessary to check up the angular adjustment of the contactor on account of phase changes in the circuit. That is a trouble which cannot be very well obviated on commercial circuits.

Dr. Craighead calls attention to the possibility of error in the measurements made with the apparatus due to distorted waves. I think there is an error, both with the shunt method and with the method under discussion. If the current wave form of the primary winding were the same as that of the secondary winding, the mutual inductance balance would produce little error. The error comes in mostly in the small quadrature component of current which produces the phase displacement. In commercial transformers the phase displacement is extremely small; usually it is something less than one degree, so that the errors in ratio are extremely small. Errors due to distortion of the primary current are also extremely small. The instruments used in balancing are in reality more important as a source of error than the method. I think that in all tests of this kind, it is important to take pains to obtain as nearly a sine wave current in the primary as possible. All commercial measurements are based on sine wave measurements, and the testing of current transformers should be carried out under sine conditions as nearly as possible. It is not a hard matter to reduce the distortion in a circuit enough to obtain good current wave forms.

In regard to Dr. Sharp's remarks as to the relative merits of mutual inductance and shunt for current transformer calibration, I wish to point out that for commercial testing floors it is necessary to have apparatus capable of as nearly continuous use as possible, and since with this apparatus the calibration of current transformers occurs but a short part of the time, it was advantageous to have it designed with a view to carrying out other important measurements, such as those that have been already described in this paper. The apparatus as laid out has numerous applications besides those which I have described. Recently it was used for adjusting a resonant shunt, which consists of a transformer having internal reactance shunted by capacitance. By means of the apparatus, it was possible to adjust the transformer until perfect resonance was obtained, and at the same time measure the true a-c. resistance.

DISCUSSION ON "THE INDUCTION WATT-HOUR METER" (HOLLISTER), DEER PARK, MD., JULY 2, 1915. (SEE PROCEEDINGS FOR JUNE, 1915.)

(Subject to final revision for the Transactions.)

W. H. Pratt: The author points out that there are two sets of eddy currents or fields to be considered and then proceeds to ignore one of these. In any complete discussion of the meter, it would be quite necessary to consider both of these effects; and since the lag angles of the resultant eddy currents are not necessarily the same, it is quite possible so to proportion the effect that compensation by special lagging devices is not even necessary. This has been done, I believe, in some cases, and certainly has been done in experimental meters.

He makes the following remark: "From an analysis of both eddy currents and fluxes involved it is seen that the torque is due to two reactions in time phase quadrature, hence approximately uniform in value." That is only a particular case. The torque would be approximately uniform in value on non-inductive loads, but when the meter is used under inductive load conditions this statement is not at all true.

There is also a discussion, more or less elementary, of the revolving field principle. The author says, "it may be pointed out that there are meters on the commercial market the action of which is due entirely to the shifting of a magnetic field." Further along he says: "A careful investigation of the construction of any, and I might say, all induction watt-hour meters reveals that such main revolving magnetic fields as are set up have their centers of rotation within the disk and revolve in a plane perpendicular to the moving element." As I understand his words, it would seem to indicate that his conception of such revolving field as might be present would be one which would have a center somewhere in the disk, but I cannot see anything to give him reason to suppose such to be the case; it is possible that I do not understand the words, although I very carefully tried to find out what his meaning may be.

Referring to Fig. 3, the author says that changing the position with reference to the rotating field, if it be so considered, does not change the direction of rotation. As I interpret his figures, it does just the thing he says it does not do, because the direction of motion remaining the same does change the direction of rotation of the disk.

As far as I can see, he attempts to make out a case against the revolving field principle and is not successful in this discussion. While I think that when we have cases of analysis, where numerical results are required, it is undoubtedly better to use an analysis similar to what he outlines—that is, consider the torque as due to two sets of fields reacting on two sets of eddy currents—I think as a physical conception we cannot at all object to the revolving field, or, perhaps it might be better expressed, a torque produced by waves of magnetic flux passing across the disk. To really get down to an ultimate analysis probably would involve

an exact knowledge of just what the mechanism of the production of torque in a variable field is.

The author attempts to make a distinction between a disk type of moving element and the drum type. To me this seems rather far-fetched. It may be worth while, but I cannot follow his argument in this particular place. He speaks of the eddy current path in the moving conductor as being practically non-inductive. This perhaps might be considered true in a very elementary discussion of the performance of the meter, but if we are going to arrive at conclusions of a character such as the paper attempts to draw, these currents can be by no means so considered, especially in modern meters, where the attempt is made to make all parts small. In fact, in order to make any numerical prediction of the performance of the meter, it is quite necessary to take very fully into account the reactance of these circuits.

There is a discussion of the effect of temperature. The author truly states that the changing conductivity of the disk is the important change as far as changing the constant of the quantities involved is concerned. The increase of conductivity of the disk increases the torque on one hand and increases the drag on the other, and while this makes a change in torque which is the largest numerical change, perhaps, of any of the effects of change in temperature, its external effect is quite nil. There is an effect, however, which is the change in the strength of the magnet, due to change in temperature, which, though in itself very small, is the principal cause of any differences in the speed of the meter due to change in temperature. It is, indeed, a small quantity, but it is the largest quantity that is externally apparent; and it is in a direction directly opposite to the direction that would be cared for by the correction which he proposes to use. Low-temperature-coefficient material practically, at least, implies high-resistance material, and high-resistance material in the potential circuit would at once lead to a large block of resulting errors which would greatly complicate matters, and with no corrections for the purpose that is here intended; in fact, the effect is in the opposite direction.

There is no discussion of one of the most important points in the meter which would have to be considered before properly discussing the behavior of change in wave form. As I read it, the mathematical statement which is outlined in connection with the elementary discussion on frequency change, leaves you in a position to state immediately a corollary that the meter is independent of wave form. Practically, that is not the ground on which you can consider the matter at all. With the induction meter the small but necessarily present eddy currents are the disturbing factors. They amount to little or nothing at fundamental frequency, but they are of increasing importance as the frequency rises. For instance, I^2R losses in the potential circuit may be important in changing the phase angle of the potential

circuit at the fundamental frequency. At the higher frequencies of the components of the current, due to the higher harmonics, these become of less importance, due to the increase in reactance, so that for the higher harmonics the resistance of the circuit becomes a negligible quantity. On the other hand, the losses which are produced in mutually inductive circuits, which are bound to be present in the iron structure, etc., produce increasingly disturbing effects. While I agree that a discussion of wave form changes in a meter is quite essential, it must be based on data which are outside the scope of what is presented in this paper. In fact, unless a meter is proportioned with due regard to these quantities, it is quite easy to obtain a device in which the wave form errors would be of a magnitude even comparable with the magnitude of the disturbing harmonic.

I want to point out that in the meters as you find them on the American market, at least, these quantities are so well considered that the errors are comparatively small. There are meters on the European market which are of such construction that the remarks which I have just made about the magnitude of wave form errors would practically apply.

The discussion of the form of magnetic circuit and the torques which will be produced thereby seems to me to add very little to the paper. I am led to make this statement because of the assumption that the distribution of the flux would be a variously assigned quantity. The author's assumption, I think, would hardly be called even approximate, and further, the type of circuit discussed is one that has long since been discarded. However, that would not prevent some results being obtained should some merit be shown in this form by reason of the analysis. On the whole, I feel that the author fails to substantiate the point which I think he makes as the principal point in the paper, the point that the revolving field method of interpretation is not an accurate one to use. I do not know that it is the best one by which to make an analysis, but I do not think it is thrown out by the evidence given in the paper.

A. S. McAllister: The author is both right and wrong. He condemns the revolving-field theory because he thinks it does not apply and he brings forward what he probably considers a new theory. There is no conflict between the theory he brings forward and the revolving-field theory. If he applies correctly the revolving-field theory, he will obtain the same results as with his own theory. It will be recalled that the single-phase induction motor can be treated as two revolving fields distributed sinusoidally in time and in space, or the field can be treated as two sinusoidally varying fields at right angles in space, ignoring the revolving feature. Identical results are obtained in the two cases. The author's theory is applicable, if properly applied, and the other theory is applicable, if properly applied—there is no conflict between the two.

C. L. Dawes: Prof. Hollister discredits the induction motor principle as applied to the watt-hour meter. I believe that the

operation of the meter can be shown to be consistent with that of the induction motor. First consider the construction as shown in Fig. 6 of the paper in which AA are the series poles and BB the shunt poles. The two fields are in space quadrature and at unity power factor, if the meter is properly compensated, the flux due to coils AA is in time quadrature with that due to coils BB. If these fluxes are equal, a symmetrical rotating field results. This will be pulsating in nature due to the salient poles. If the fluxes differ in magnitude an elliptical field having its major axis in the direction of the stronger field, results. If the power factor of the circuit is not unity the elliptical axes will undergo displacement. In any event the moving element will have the slip-torque characteristics of the induction motor as shown in Fig. 1, herewith. The rotor in this case has a high resistance and a low reactance.

Assume that *ob* is the slip-torque curve for some particular load and that *ad* is the speed-retarding-torque curve of the rotating element, the speed being in terms of rotor slip. b' will

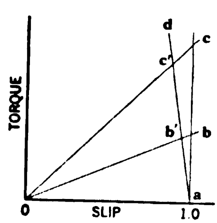


FIG. 1

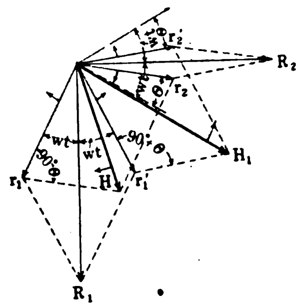


FIG. 2

then be the point of operation. Any tendency of the element to approach synchronous speed will be accompanied by a reduced driving torque and an increased retarding torque, so that the speed element must drop back to b', the point of equilibrium.

Assume that the load being registered by the meter be doubled. First if the potential and current both be doubled, the torque will be quadrupled as in the case of the induction motor when the potential is doubled. But if the current alone is doubled (power factor constant) the driving torque is only doubled at each value of slip as shown by line *o c*, Fig. 1. The meter will now operate at point c'. When the slip at full load is of the magnitude of 98-99 per cent the element speed at point c' may be considered as having been doubled. That these conditions are true may be proved analytically as follows:

Let R_1 and R_2 (Fig. 2, herewith) be the instantaneous values of the fields due to the current in the potential coils and current coils respectively, at time t. R_1 and R_2 will necessarily be in

space quadrature. Resolve R_1 into two components r_1, r_1' each of which is equal in magnitude to one-half the maximum value of R_1, and which rotate at an angular velocity ω $(= 2\pi f)$ in opposite directions. Let r_1 rotate clockwise and r_1' counter-clockwise. Then at time t each will have rotated through an angle ωt as shown in Fig. 2, and their vector sum will be equal to R_1. Likewise R_2 may be resolved into two components r_2 and r_2' revolving in clockwise and counter-clockwise directions respectively. Assuming that the current lags an angle θ behind the voltage, at time t, r_2 and r_2' will have only passed through an angle $(\omega t - \theta)$. By combining the vectors which rotate in the same direction a field H rotating in a clockwise and a field H_1 rotating in a counter-clockwise direction are obtained.

By geometry—

$$H^2 = r_1^2 + r_2^2 - 2\, r_1 r_2 \cos(90° - \theta) = r_1^2 + r_2^2 - r_1 r_2 \sin\theta$$

$$H_1^2 = r_1^2 + r_2^2 - 2\, r_1 r_2 \cos(90° + \theta) = r_1^2 + r_2^2 + r_1 r_2 \sin\theta$$

since $r_1 = r_1'$ and $r_2 = r_2'$

$$H_1^2 + H^2 = 2\,(r_1^2 + r_2^2) \qquad \textbf{(1)}$$

$$H_1^2 - H^2 = 4\, r_1 r_2 \sin\theta \qquad \textbf{(2)}$$

Let p be the angular velocity of the disk. It will evidently rotate in the direction of the stronger field H_1.

Let T be the torque due to H.

Let T_1 be the torque due to H_1.

Let T_2 be the damping torque due to the permanent magnets.

Then
$$T = -K\, H^2\, (\omega + p)$$
$$T_1 = K\, H_1^2\, (\omega - p)$$
$$T_2 = -K'\, p$$

where K and K' are constants.

T and T_2 are retarding torques, hence the minus signs.

For equilibrium—

$$T_1 + T + T_2 = 0$$

$$K\, H_1^2\, (\omega - p) - K\, H^2\, (\omega + p) - K'\, p = 0$$

$$K\, \omega\, (H_1^2 - H^2) - K\, p\, (H_1^2 + H^2) - K'\, p = 0$$

Substituting from **(1)** and **(2)**

$$4\, K\, \omega\, r_1 r_2 \sin\theta = 2\, K\, p\, (r_1^2 + r_2^2) + K'\, p$$

$$= 2\, p \left[K\, (r_1^2 + r_2^2) + \frac{K'}{2} \right]$$

The term $2\,p\,K\,(r_1^2 + r_2^2)$ is a retarding torque due to the disk spinning in an a-c. field and may be made negligible by not operating the meter at too high a gap density.

Since $\qquad r_1 \propto E$ and $r_2 \propto I$,

$$E\,I \sin \theta = K''\,p, \text{ where } K'' \text{ is a constant.}$$

If the flux of the potential coil is made to lag 90 deg. behind the impressed voltage E, then

$$E\,I \sin (90° - \theta) = E\,I \cos \theta = K''\,p$$

or the angular velocity of the disk is proportional to the power expended in the circuit.

One of the fields B may be removed and obviously the foregoing characteristics will change in magnitude only. The cylinder may be split along an element in Fig. 6 of the paper, and rolled

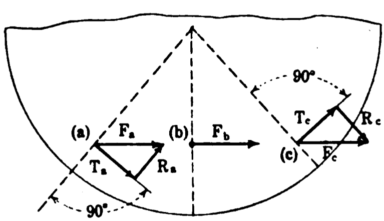


Fig. 3

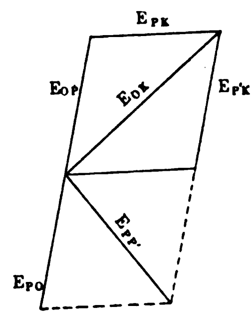


Fig. 4

out in a plane, the three poles $A\ B\ A$ likewise being made to fall in a straight line. Coil B may be placed the other side of the strip for mechanical reasons and a sliding field, as shown in Fig. 2 of Prof. Hollister's paper, results. The center of the rotating field is now at infinity rather than on the disk as stated by Prof. Hollister. The force-slip characteristics of this field will be the same as those of the rotating field of which this is a development. If a pivoted disk be substituted for the developed cylinder the force-radius will be slightly less than that for the cylinder of the same radius, because the field does not act tangentially at every point as shown in Fig. 3 of this discussion, where F_a, F_b, and F_c represent the driving forces of the sliding field at points a, b, and c, respectively. F_a may be resolved into a tangential component T_a, and a radial component R_a, T_a alone being effective in tending to cause the disk to rotate. Likewise F_c may be resolved into two such components. This changes the torque but slightly, but does not change the characteristics of the meter. To my mind the foregoing demon-

strates that the induction type meter behaves in every way as an induction motor of similar constants.

I should like to make a slight criticism of Fig. 10 in the paper. I think that a greater degree of clearness would have resulted if the nomenclature on the diagram had been made to conform more closely to that of the circuit represented in Fig. 9 of the paper. Then again it is impossible to obtain the quadrature relation between the voltage across the resistance and that across the reactance coil, due to the losses in the resistance coil. Therefore, I recommend that Fig. 10 of the paper be drawn as shown in Fig. 4 herewith, noting that points O and O', and p and p', are at the same potential, respectively.

Then $$E_{OK} = E_{OP'} + E_{P'K} = E_{OP} + E_{PK}$$

and $$E_{PP'} = E_{PO} + E_{OP'} = - E_{OP} + E_{OP'}$$

In my opinion this subscript notation is more explicit than the looser notation employed in Fig. 10. In order to have E_{PP} in quadrature with E_{OK},

$$E_{OP}/E_{OP'} = E_{PK}/E_{P'K}$$

D. D. Ewing: I feel diffident about discussing this paper, inasmuch as the author is absent. One of the things I desire to call attention to may possibly be only a little personal objection. On the first page the author says: "The principle, therefore, reduces to the action of the d-c. motor, *i.e.*, a current-bearing conductor placed within a magnetic field." I think he has narrowed the application of this principle down to too small a field. In the ultimate analysis, all torque is due to that, whether a-c. or d-c. motors are considered. I do not think we should go on record as trying to limit the principle to a certain type of motor, because it is a general law. Dr. McAllister pointed out a few minutes ago that both methods of explaining the operation of the meter are correct if followed out to their conclusion. As a teacher of electrical engineering, I often feel it necessary to present a subject in several ways. One man understands the thing when presented in one way, and another man understands it best when presented in another way. Thus in presenting the subject of induction watt-hour meters, I often feel it to be necessary to present the theory in two ways—one from the standpoint of the rotating field, the other from the standpoint of component fields. If worked out on the component field basis the speed e. m. f. in the disk must be taken into account, although its influence is not very great. As the last speaker pointed out, the slip is very great. I believe in some of our commercial 5-ampere meters, the full-load rev. per min. of the disk range between 30 and 40. Reduced to a motor basis, that would mean

a slip of about 95 per cent. The speed e. m. f. therefore, while present, is not large.

In connection with this idea of reducing the meter problem to that of the induction motor, I do not see as clearly as does Mr. Dawes, that the center of rotation of the revolving field is at infinity. As I see it, the field is traveling at an angular velocity measured in rev. per min. which is the same as if there were arranged in a circle, a number of poles, $\frac{\text{circ. } A\ B\ C}{\text{arc } A\ B} \times$ No. of poles in arc A B. (See Fig. 5, herewith). In other words, in some meters the poles occupy approximately one-quarter of the circumference, and you have three poles; that means, as far as the revolving field is concerned, a 12-pole meter and a synchronous speed at 60 cycles of 600 rev. per min. Another thing—my conception of the

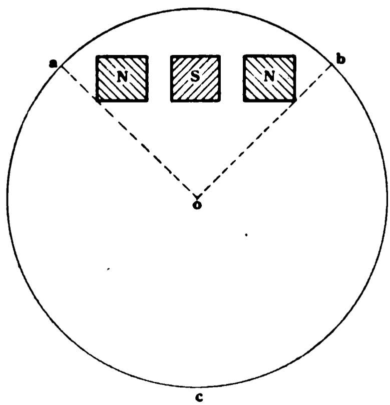


FIG. 5

analogy between the induction motor and this meter is, that if we take an induction motor with a rather large number of poles and place upon the rotor some material which is a perfect magnetic shield, covering up all the rotor but three pole spaces, we would have the same condition as with the induction meter—we would get rotation, but it would not be a very good motor.

Clifford W. Bates: I would like to point out a similarity between Figs. 1 and 11 of the paper. In Fig. 1, two current poles and one potential pole are shown, while in Fig. 11 we have one current pole and two potential poles. Let us consider the figure shown by Mr. Dawes. If one of the potential poles is removed, Fig. 1 will result; while Fig. 11 will be obtained by removing one of the current poles. Thus, they are both special cases of the same general form, and if the idea of the shifting field holds in one case, it must in the other, which is entirely contrary to Professor Hollister's conclusions.

Professor Hollister gives in Fig. 5 a vector diagram which purports to represent the action of the meter. This diagram is quite incomplete and does not even show all the angles and points which he mentions. Professor Jansky, of the University of Wisconsin, gives, in his book, "Electrical Meters", a vector diagram which does illustrate correctly and completely the action of this type of meter.

M. G. Lloyd: I think first of all that this distinction regarding the rotating field is rather academic—the distinction the author tries to draw between the rotating field and another theory is not fundamental. That point, however, has been sufficiently covered by the other speakers, and perhaps also the point in regard to the statement that we ought to be able to get synchronous speed if it is acting on that principle. Of course, we only get synchronous speed with zero load, and as we have this meter very highly loaded, we cannot approach that.

In regard to these other analyses in respect to the effect of temperature, frequency, wave form, etc., it seems to me that they are very superficial. The author has taken account of the more obvious things, but has not gone into details which really determine the action of the meter, as Mr. Pratt, in particular, has brought out. In the first place, he seems to have one particular type of meter in mind all the time, and these small effects enter differently into different types of meters. One meter may vary in one direction by a change in frequency and another may change in another direction by the same variation in frequency. The changes are small, but involve things which the author has not considered at all in his theory. Similarly with wave form, small differences in wave form produce almost no appreciable result. On the other hand, by using a sufficiently distorted wave, very observable effects have been obtained. Such results are available in the literature on the subject, which the author does not seem to have considered.*

*Rosa, Lloyd and Reid, *Transactions International Electrical Congress*, St. Louis, 1904, Vol. I, p. 555.

DISCUSSION ON "THE BEST CONTROL OF PUBLIC UTILITIES" (BAUM), SAN FRANCISCO, CAL., JANUARY 22, 1915, AND "CLASS RATES FOR LIGHT AND POWER SYSTEMS OR TERRITORIES" (BAUM), DEER PARK, MD., JULY 2, 1915. (SEE PROCEEDINGS FOR JANUARY AND APRIL, 1915.).

(Subject to final revision for the Transactions.)

DISCUSSION AT SAN FRANCISCO

A. H. Babcock: The paper is an argument for class rates in charging for electric service, *e. g.*, one set of class rates to apply to an entire power distribution system, regardless of local or competitive or geographical considerations; the rates in the different classes to be determined by, first, demand charges—that is, interest, maintenance, depreciation, operation and management; and, second, energy charges, which shall include only those items that are proportional to the kw-hr. output of the plant. The paper makes no attempt to determine the rates for the different classes, but merely is an argument in favor of class rates. In support of these arguments the author cites the different conditions under which passenger and freight rates are determined by a railroad company, and states that because of the great natural difference in the service rendered there is no confusion on the part of the public with reference to the justice or the equity in the differences found between those two generic classes of rates.

The author ignores the existence of different class rates for freight transportation, and he overlooks, apparently, the very significant underlying reasons for the great variations in freight classification and rates. Apparently he bases his arguments for power rates on the hypothesis that certain capitalists have certain moneys to be invested for profit in a power transmission and distribution system; and that by some means or other a profit must be secured on this investment, whether or not the particular locality to be served is ready for such development and willing to receive it, or whether the plant is to be, or, in the case of an existing plant, has been, designed with due regard for the natural economies in engineering and construction. It would seem that a far more just determination of such class rates, and a much stronger presentation of the necessity for such class rates, might have been advanced if the author had stated some of the principles upon which freight classification is determined and the rate for the transportation thereof fixed.

In the first place, a freight rate is a price charged for changing the location of something, just as a manufacturer's rate, whether he manufactures goods for sale or power for sale, is a price charged for changing the form of something. For useful purposes we must have things in the place where they can be used, as well as in the form they can be used; and whoever changes either the form or the place in this connection adds value to the article, and is entitled to a profit for so doing. The power company in generating and distributing electricity does not change the energy

itself, but merely changes the form thereof; that is to say, water falling down hill, or oil burned under a boiler, is converted from mechanical or chemical into electrical energy; the power company changes the location of the energy by making it available for use at the point where the consumer desires to use it. Now, the consumer is not concerned in any way with the expense of making these transformations; he is concerned with only one thing, viz., the value of the energy to him at the point of consumption, and the *value added to the energy* in bringing it from the unusable form at the wrong place to a usable form in the right place is what determines the *value of the service* rendered by the public utilities; and the value of this service, not the cost of it, is the true measure of the price to be charged for it.

Assume for the sake of argument that all electric power was generated as a by-product from some other and major operation —the Los Angeles aqueduct, for example. This power is not valuable in any sense, that is to say, it is not usable by the manufacturer; it is not valuable to him personally merely because he cannot use it; but, if he can transport it to places where it can be used, and supply it there in the form desired by different people, the value of his service and the price that he can charge for it are determined by its value and usefulness to the consumer. It is worth a certain amount to a railroad company for transportation, both of passengers and freight. It is worth a different amount to a chemical works where the load is constant throughout the twenty-four hours. It is worth a different figure to a lighting consumer, and worth still another figure to a small power consumer. If the author were connected with a public utility supplying power in Los Angeles, where the aqueduct by-product is available, would selling prices, in competition with him, based on the cost of service, appeal to him? The manufacturer of this by-product can sell at only the price or prices that will develop "eagerness and ability on the part of the consumer to purchase" his by-product, or he cannot sell it at all. In other words, the cost of the service does not enter at all into the determination of the rates he can charge. This principle is sometimes called charging "what the traffic will bear," but it is not; it is charging what the traffic can afford; and the difference between the two statements is easily ascertainable. On the other hand, what the traffic can afford is just enough less than what that service is reasonably worth, so that a profit is left to the purchaser of the commodity; in which event, if a profit is still left to the producer, men and capital will be induced to undertake such enterprises. If this profit to the manufacturer is not left, then the market is not yet ready for the enterprise.

To take another illustration of the fallacy of basing rates exclusively on the cost of service: as a part of the original development of the Standard Electric Co., it was proposed

to utilize the tail water from Electra for irrigation purposes in the Sacramento Valley. Assume now that a company with capital sufficient for the enterprise could build such an irrigating system, legally, without interference with other water users along the Mokelumne River, and that this company should approach the author with a proposition to purchase the Electra tail water, by a diversion at the tail race, with no cost to the author's clients. Would he recommend a sale of this water at the cost of service, or would he endeavor to estimate how much water the irrigation company could sell, at what prices the farmers could afford to purchase, what would be the overhead expense of the irrigation company; in short, would he endeavor to find how much this particular water traffic could afford? The answer is so easy that further discussion of it would be puerile. But the author of the paper contends that rates should be based on the cost of service plus a profit. If so, what cost?—it is proper to inquire.

There are at least two ways of thinking of the cost of a service—first, that used by the author, which includes the demand charges and the energy charges, and therefore the entire cost; the second is the cost of those items that vary directly with the output of the plant, which is sometimes called the additional cost, or, to borrow a term from Acworth, the railroad economist, the "out of pocket" expense. The application of these two costs to the science, or art, as perhaps it is better called, of rate making, can be easily seen by considering the very well known case of an established industry—a power generating and distributing system, for example—which is serving a given territory. The cost of operation of this system would be covered by what is stated above as the entire cost. Let us assume, then, that as usual there is a large depression in the load curve during certain hours of the day, and that fortuitously a large consumer is found whose requirements for power will just about fill up this big depression. Obviously to take on this customer requires no more overhead expense, the fixed charges are not appreciably increased, and the only expense to the manufacturer by reason of this additional load is for those items of his operating expense which vary with the kilowatt-hour output of the plant. This is the additional cost. Now, if the rate to this consumer is to be based on the cost of service, shall it be based on the entire cost per kilowatt-hour output of the plant, or shall it be based on the additional cost per kilowatt-hour covering this period of depression in the load curve? If the power company encourages the purchase of such power, and, finding the business attractive, sells at the additional cost, will it not be accused of discrimination, and does it not stir up trouble for itself, the public arguing without discernment that if the power company can sell at this very low rate to one, it can equally well afford to sell at the same rate to all its consumers? In other words, will the public not demand that these same rates shall serve

as the basis for all rate making? Precisely the same argument applies to extensions from an existing plant into territory not now served, where the market is very limited at the present time, but where it may be expected to develop under proper treatment. As a matter of fact the rate the power company will charge for such service may be a normal power rate, having the entire cost of the plant as its basis; or it may be a sub-normal rate, having only the additional cost of service as its basis. The particular rate that will be chosen to cover such cases will depend on the value of the service to him who buys it. The additional cost evidently is the danger line below which an over-ambitious salesman must not drop under any conditions; and under certain conditions it may not be prudent to go even below the entire cost because of the tendency of the public to require comparison of rates regardless of conditions, and the danger that the regulating bodies may be compelled by political considerations to force rates elsewhere on the sub-normal basis when the normal rates are clearly justifiable. This consideration may often deter an enterprise from developing new territory.

Certain communities, by reason of location convenient either to very low cost fuel supply, or to an abundant hydro-development, are so situated that only by quoting on the basis of the additional cost can attractive rates be made. It is evident here that the value of the service to the customer is what fixes the rate, and equally evident that this community is entitled to the lower rate its advantageous position secures to it. It is also evident that a power-transmission system supplying this locality should be entitled to take business at the sub-normal rate of additional cost only, without being compelled unjustly to spread these same rates over its entire output regardless of local conditions. This argument alone, seems to dispose effectually of the author's contention for identical rates for a given class of service regardless of geographical position. It is as unjust to expect the lighting rate shall be the same, for example, in all of the towns he has cited, as to expect that the lighting and power rates should be identical in that same town, regardless of the different uses to which the energy is put, and consequently of the different values to the different customers. Power rates, then, to be reasonable, can no more be the same for the same service in different localities than can transcontinental freight rates from the Atlantic coast to Salt Lake be as low as to San Francisco, and for precisely the same reasons. Community of interest, plus the natural physical advantages of one locality over another, is what causes bees to swarm, and men to congregate in cities. Such natural advantages are as immune to artificial or legislative interference as are the phases of the moon.

Furthermore, the attempt to base power rates on the cost of service has been, in the opinion of many persons, the direct cause of much legislation against legitimate enterprises, they suffering with the illegitimate ones, which, by combination of large

blocks of water in the securities, have rolled up enormous fixed charges that have been assessed against the communities served. We have only ourselves to blame for much of the popular misunderstanding and hard feeling directed against us.

The author's paper is not an argument for any specific rates, but merely for the establishment of classes for rates to hold over the entire system. It is not proper, then, at this time to bring about a discussion of what constitutes reasonable rates under varying conditions, but in any such discussion and bearing directly upon it much can be learned by a study of the method of making freight classifications and freight rates as applied by the railroads. In considering this statement it should be remembered that the railroad industry is much older than the power industry; that the art of rate making is the result of several generations of hard study and earnest efforts; and that the principles underlying the determination of power or freight rates must be the same, because they deal with the same thing, viz. the value added to something by changing its form or changing its location.

Based on this argument, it would seem that the author's plea for class rates is just, for the reason that any *average* rate that might be considered fair would limit the use of electric power in many manufacturing establishments, because it would be too high; that is to say, the assumed value would not be the value to the consumer; while on the other hand, it would be much lower than the value of the same product to other consumers. It is not practicable to go to the other extreme, and make a special rate for every individual consumer; but it is possible to divide all consumers into certain classes. They may be more or less in number than the author has chosen, but within a class, a rate must be given that will encourage the use of electricity in that class, not only in the manufacture of those articles to which the use of electric power will add the most, but also to which it will add the least in value; the latter class being the one that will fix the rates to all kinds of manufacturing in that class (the word "manufacturing" being here used in the broad sense). In fixing the rate for any given class the power company will sometimes be obliged to put its rate below the entire cost and yet not so low as the additional cost, the result being a sub-normal rate, less than reasonable, but necessary on account of the conditions surrounding the enterprise, and justifiable only under those conditions. Under other conditions at the other end of the scale there will be found cases where the value of the service is sufficiently great, and the rate may exceed the entire cost of service, in which case it is a normal and a reasonable rate, fair and just to all concerned, although it may be higher than the rate for some other class of service, or even for the same class of service under other conditions.

These are precisely the conditions that determine the particular rate charged for freight haulage by the railroads. The

arguments advanced herein, far from being original, are largely paraphrased from an admirable paper on the railroad rate question recently printed and distributed by the *Railway Age Gazette*. They are given here in the hope that some of those who question their equity in freight rate making, but who understand them in power rate making, will come to see the close analogy between the two, and therefore will be able to judge justly; and to see, that after all is said and done, the public utilities are all in one big family, and that it is as much our duty, as officials of such companies, to meet and to discuss just such problems as these as to argue our engineering problems.

Discussion at Deer Park

William J. Norton: I think it is well for those of us who live in the East to realize that quite important strides have been made in California in rate making within the last year. The California Commission itself has probably gone further than any other commission in theoretical rate making.

I believe that there are serious difficulties in attempting to apply pure theory to electric rates. Electric rates are complicated for many reasons. In the first place if we start to make rates on a pure cost of the service theory, such rates must be modified at the maximum end of the scale by reasons of policy, either on account of the pressure of public regulation which generally affects the maximum rate only, or from what the companies themselves consider as good public policy. On the other hand at the low end of the scale if we fix rates by a cost analysis we again find that we must modify the rate to be charged because in many instances the rates set by theory would not get the business. Again in building up our theoretical calculations for rate making, many arbitrary assumptions must be made that give us a result which is an average cost and not a real cost. Such a result may be used from year to year for comparative purposes but it is not practical as a direct method for rate making.

Therefore, with the upper end of our average cost curve adjusted by policy and the lower end modified by expediency, the rate makers' particular duty is to adjust the curve between the two points and make the entire schedule logical, so that in the end we abandon our cost theory altogether. The most important thing in electric rate making at the present time, it seems to me, is to abandon the idea that practical electrical rates can be made as the result of pure mathematical calculations. The best result comes from studying each individual rate schedule, which upon examination we find to be the composite growth of both theory and practise generally developed during the time when little was known about diversity factor or load factor, and our first effort in adjusting such a rate schedule must be to make the rates simpler, not only so that the public may clearly understand them, but also so that they will be more easy for the companies to administer.

Mr. Baum has not placed much stress upon this feature of rate making, but, as someone has said: "Rate making is an art and not a theory."

H. L. Wallau: The advantage of uniform rates for various municipalities fed from one large system, in contra-distinction to local rates in each, based on both general and specific investments required for the several localities is obvious, and its carrying out, good policy. Likewise the desirability of giving the same rates to similar classes of customers is self-evident. But if I understand the paper correctly, it is proposed to establish class rates on an average basis for the class, namely, a flat rate per kw-hr. If my interpretation is correct, then I take issue with the author. In my judgment a rate should always recognize load-factor. If it does not, it may result in a gradual building up of a large investment which would necessitate a rate-revision upward—a very difficult and from the public point of view a most reprehensible thing to do. While a plain meter rate with discount applied in some form recognizes use, it does not recognize load factor. A 50-kw. consumer using his load on an average of 360 hours per month is certainly entitled to a better rate than one who operates the same kind of installation, but makes a demand of 100 kw. with but half the hours of use.

Mr. Baum's method of computing fixed charges necessitates the separate metering of light and power in order that the fair return may be made on the total investment. Personally, I prefer a schedule which applies to either or both, requiring but one set of meters (in most cases) and giving the consumer the benefit of the diversity between his lighting and power demand, when jointly metered.

For all practical purposes, the company with which I am affiliated has but three schedules: (*a*) Wright demand schedule for residential consumers; (*b*) Wright demand schedule for small commercial lighting and power consumers below 5 kw.; (*c*) Hopkinson schedule for consumers above 5 kw. and without limit as to ultimate size. The largest consumers on this schedule at present are of about 2000 kw. demand.

Each of these schedules recognizes the individual consumers' load factor, and this recognition makes for a constantly improving operating load factor. The last schedule has two steps in the demand charge, that is, automatically gives the discount for size, and a number of steps in the unit rate, giving a discount for quantity, that is, for load factor.

By properly selecting both sets of factors, the diversity between large and small consumers is introduced, and the resulting rates are satisfactory over the entire range.

We hope some day to be able to operate under a single schedule which will be applicable to all classes of consumers, and which will recognize in the rates and terms and conditions all of the factors involved, such as time of use, diversity, individual and collective, load factor, power factor, etc.

M. G. Lloyd: I think that most of the principles upon which Mr. Baum has worked are well recognized and will not be seriously disputed. I am not quite clear, however, whether in making rates, as he has proposed, to cover a large district, he means the plan to apply only in such cases as I think are rather frequent in California, where a single company covers a large district, operating in a number of municipalities there, and in which the local costs would differ according to the distance of transmission, substations involved, etc. What might be applicable in that case, however, does not seem to me as applicable in a similar district which is served by two or more different companies, with possibly two of them even operating in the same community, that is, having overlapping territory. From what the author says, in some places in his paper, it appears to me that he meant his system to apply to such conditions also. For instance, in the case of two companies whose territory was entirely the same, if the charges were made the same where the costs were not the same, it would mean, of course, that the charges would have to be high enough to cover the conditions of the least efficient company, or if they were fixed the same for both companies, lower than, that, it would mean that one company would eventually become bankrupt. It does not seem to me that all of these advantages and disadvantages that are pointed out in the summary here can be supported. In regard to rewarding an efficient company, which is not done on the ordinary basis of making rates which are simply sufficient to cover the cost of service, in which is included, of course, interest on investment; it seems to me that can be much better accomplished by such a method as is in vogue in Boston for gas service, where there is a corresponding change made in the interest allowed and in the rate at the same time; that is to say, whenever a company can reduce its rate for service it is automatically allowed a higher rate of return upon the investment.

There is a provision in the public utility laws of at least two of our states, I know, providing for efficiency; that is, the principle is recognized in the law that efficiency in operation and consequently in lowering cost shall be recognized by larger returns, although I must say that I do not think any, or at least very little progress has been made in applying that principle in rate-making by commissions.

In regard to the classes of service that were outlined by the author, there is one rather important class which was suggested by the first paper presented at the session this afternoon. It seems to me that the heating and cooking load should be put in a distinct class by itself, because it represents a definite condition of service, which is rather different from the other classes which have been recognized in the paper; that is to say, its diversity factor is different from that of the residence load which is made up merely of lighting and small applications of power, and yet in other features it is more like the residence conditions. It

appears to me desirable that such service should be separately classified, and either a special rate made for it or else a rate made in such way as has been mentioned here as applying in Spokane, where the practical result is equivalent to giving a special rate for the use of energy in heating and cooking.

S. N. Clarkson: This question of class rates for territories seems to have been brought up to cover a condition on the Pacific Coast, and which will hardly be met with elsewhere. When Mr. Baum proposes to fix a certain class rate for a territory, irrespective of the distance from the source of power, he neglects entirely the cost of distribution, which is much more important and many times as great as the actual cost of generation. The author says: " The grocer and butcher do not vary charges by distance of delivery." This is true within certain limited territories, but tradespeople do not generally deliver goods to one customer several miles off the regular delivery route without making some extra charge.

The author further states: " For example, residence lighting in Sacramento and Stockton should have the same scale of rates —except as local cost of overhead and underground distribution may vary, or where natural conditions or competition may have produced unusual conditions." Then a little further on he says: " Rather than have a large number of different scales with slight differences, it is believed it will be better to have a uniform scale." These two statements do not seem to be consistent. The first statement seems quite reasonable, and I believe the rate must vary when the cost of distribution and local conditions are materially changed.

The author refers to rates being different because a new substation or distributing system was installed, but it has been my experience that the cost of such additions is usually covered by getting new business rather than increasing the rate on existing customers. It seems to be generally conceded now by all the interested parties that any economies, which can be effected by efficient organizations and economical equipment, should be divided between the company and its consumers.

W. H. Pratt: The analysis of costs in the paper may have been with a particular point in view, which to my mind seems to be that of full recognition of the fact that charges must be based on some form of demand system, and yet that that demand system should be so planned that changes which might occur in the future, at which time a revision of the estimate might properly be made, would not upset the conclusions that would then be drawn.

Edward L. Wilder: There is one point, already mentioned in the discussion, which I think is worthy of some amplification. It is very important, it seems to me, in rate making, to furnish an economic motive to the consumer to improve his load factor. It does not seem to me that the method here proposed does that. There are several examples which occur to me. For instance,

the adding of household devices decidedly improves the load factor of the ordinary residence, and if it is possible to devise a rate schedule which will encourage the use of such devices both the consumer and the company are benefited. I have in mind one case where a very large factory this last winter was working on short hours because of the financial depression. The rate schedule under which they were working included an off-peak option, which meant a concession in case any of the demand was dropped during the station peak. The factory, by arranging its hours of work to suit the rate schedule, was enabled to save several hundred dollars a month and still get the service which was required. This was of as much advantage to the power company as to the consumer.

James W. Welsh: We have tried the method the author presents, in Pittsburgh to a limited extent, and find it very successful. I think the author's principal point is in the method of prorating the demand charge or the fixed charges among the various classes of service. It seems to me that this is a very simple and complete plan. It has several advantages which I do not believe have been mentioned, in addition to that of automatically eliminating the necessity for considering the load factor and diversity factor. I refer to his formula where the demand for this class is prorated on the basis of the ratio of the peak load of that class to the sum of the peak loads of all classes. That method also takes care of the question of reserve capacity, both in generating equipment and in transmission lines and substations; in other words, it eliminates the necessity for knowing just what that capacity is in putting the charge on a kw. basis. It may be a difficult thing to know what the capacity of the transmission line is, when you charge your customers so much per kw., but this method starts with the fixed return which must be earned and prorates the charges on that basis.

H. M. Hobart: In the main I consider that the author's recommendations are sound and desirable. As near as I can see, they are precisely on the lines on which railway rates are made up, and they will involve the same difficulties, perplexities and paradoxes that are therein met. It is quite customary, and to a certain extent right, to lay a great deal of emphasis on load factor, but there are other things which in the last analysis affect the costs besides those mentioned. I have in mind particularly the power factor of the load. We do not discuss that much in America, but I know that engineers in Italy have written papers and devised systems that would take into account the consumers' power factor. It is of far-reaching effect. If a man who wanted only some 30 h.p., chose to look into the matter, and happened to be interested in electrical subjects, and able to make calculations, he would probably find that if he bought a machine as large as a 100-h.p. motor and used only 30 h.p., and had the motor designed so that the saturation was low at normal operation, and if he ran it with a leading power factor as low as 0.2 or some-

thing of that order, the supply company could afford to pay that man a sum for every kw-hr. he took from the system instead of charging him for the amount he consumed. That would be in the nature of an equitable transaction. That, doubtless, as time goes on, will have to be taken care of—the general influence of the power factor of the load will have to be considered. In most cases of a lagging load, averaging say 0.4 *power* factor, even if the *load* factor is high, the actual cost would be greater to the company than a load of unity power factor with lower load factor. Such matters are very difficult to determine. You can only, in a way, keep track of the tendencies. Mr. Baum's paper evinces a realization that it is hopeless to distribute the charges equitably. Indeed there is no very acute need that each customer should pay to the last farthing exactly the equitable amount.

The chief requirements are that the community shall be efficiently provided with electricity, and that the supply company shall obtain a reasonable return for its undertaking. The plan outlined by Mr. Baum will necessarily involve, as all progressive plans do, the cruel but wholesome necessity of putting inefficiency out of business.

The author makes it clear that he intends the system to apply to competing companies in the same district. I will refer to one case the author speaks of, where a man on one side of the street gets his supply from one undertaking and a man on the other side of the street gets his supply from another undertaking. It would be utterly inequitable, in such a case, that the one man should pay a different price from the other man.

That which especially interested me in this paper is the clear way the various matters are brought before us—the point that you must distinguish what kind of plant you put down, you must realize the possibilities of the district, what the percentage of poor load factor will be, and what percentage of the consumption will have a good load factor. It might make all the difference in deciding between a steam central station and making use of some water-power prospect. There is usually certain to be a considerable percentage of lighting load and the author shows very clearly in Fig. 3, as far as regards the lighting load, the water-power plant will not be in such a good position to compete as the steam undertaking, whereas as regards the power load, the water-power undertaking will be in a better position to compete than the steam undertaking, provided it does not require too great an outlay for water storage or steam reserves. The further west we go, the more favorable is the case for water power, and the further east we go, the better is the case for steam. There will be a dividing line where, in order that investments shall not be wasted, very careful analyses should be made. In this intermediate zone it will frequently occur that a very large steam undertaking will be in competition with a very large water-power undertaking. We may assume that in both cases the plants would be first-rate,

put down with the best engineering knowledge, no waste in any way. Under such conditions, in arranging for the price a commission would have very hard work so to arrange it that the steam undertaking should not get a disproportionate return for the lighting load while the water-power undertaking would lose on the lighting load and obtain a disproportionate return on the power load. These questions are, however, in no sense any more difficult than the questions involved in the making of railway rates.

Ralph W. Pope: The author appears to be on the right track in making different charges for different classes of service. It is one of the most difficult problems in so fixing rates that the company will derive the greatest revenue. If they are too high, they may diminish the demand, and if they are too low, the margin of profit is too small. Somewhere there is an actual dividing line between the two conditions, which is very difficult to determine. The author has referred to railroads and delivery service in cities in a way that shows that there are difficulties in almost every branch of business in meeting the wishes of the customer and at the same time bringing proper returns to the producer. Railroad charges have had much to do, I think, with the establishment of the public service commissions.

In the case of railroad rates, the author has cited the railroad as not charging for certain improvements which had been made. This may be generally the case, but after the Pennsylvania Railroad spent one hundred million dollars on tunnels and tracks leading to the station in New York City, New Jersey passengers were taxed ten cents each for going through the tunnel, southern and western passengers being exempt from that charge.

As an instance of the question of rates, I might cite right here that the Baltimore and Ohio R. R. will carry me from Deer Park to Asbury Park, about 75 miles further, for the same price that the Pennsylvania will carry me the lesser distance. In another case the rate to Washington and back from New York City is about $10, and the distance is 230 miles each way, making 460 miles for $10, which is approximately two cents a mile. In the summer season the railroad companies make an excursion rate of $3 for the round trip, which is less than seven mills per mile. This means a special train and poorer accommodations, but it shows that under certain conditions they are willing to advertise and get people to go, when the people had not intended to go, for seven mills per mile, but if you want to go at your own convenience by a regular train the fare is two cents a mile.

There is one other illustration which has come up before in some of our discussions regarding different conditions. Mr. Baum in his paper refers to the California experience, while the conditions in the eastern territory are different. In the irrigation projects in New Mexico and Arizona a very low rate is made for domestic power for heating or any other purpose in the winter, because there is no use for the power for irrigating in the winter, while the price of coal is very high, and so a low rate is

made to compete with coal, which would be impossible under any other conditions.

M. G. Lloyd: I think that last point perhaps explains what Mr. Hobart did not seem to see in presenting the paper. One may have a seasonal load, like irrigation, which is very desirable from the standpoint of the power plant, and yet as shown by the figures, it has not the characteristics that would earn concessions on the same yearly basis as the other loads; yet it is entitled to it as an off-peak load. The same thing applies to an all-year daylight load. It has not a 100 per cent load factor, but is more desirable than a load with 100 per cent load factor, because it is off the peak.

H. L. Wallau: There is one more point I would like to bring out in reference to the load factor rate versus the direct flat rate. An illustration was called to my attention some time ago of a company in a small town, whose business was chiefly lighting. They had the usual Saturday night peak, all the year round, the heaviest night in the week, and it was particularly heavy in the winter time. There was a clothing concern in town, the use of whose load during the whole week was very moderate, but on Saturday nights the use of their load was quadrupled by outline lighting all over the building, the very time when the company could least stand it. They were making a terrific demand on Saturday night, with a very low use of their load during the week-day nights, and having a flat rate, with discounts, they got a good deal better rate than if they had not put up the outline lighting on the building which they used on Saturday night only. That is an inconsistency, and such a class of rates is apt to build up just that sort of business, and when that business gets big enough there is nothing for the company to do except raise rates, if they want to avoid a deficit.

DISCUSSION ON "RATES AND RATE MAKING" (LINCOLN), NEW YORK, OCTOBER 8, 1915. (SEE PROCEEDINGS FOR OCTOBER, 1915.)

(Subject to final revision for the Transactions.)

William McClellan: I am interested in the theory of the maximum demand meter, and I hope Mr. Lincoln will pursue it, so that we can get a good type of maximum demand meter. It is needed, but the inference that it is universally needed is not in my opinion true. It is my firm belief that rates and rate-making is about ninety-five per cent commercial and about five per cent engineering. We have got to have a certain amount of general information along engineering lines to understand what a true rate should be, but our commercial men, who familiarize themselves with fundamental facts, are the men best qualified to make rates.

The amount of engineering knowledge that they must have is very small indeed. It is true that anybody who starts out to make a rate soon learns that no matter how he expresses his rate, whether as a so-called flat rate, or the so-called Hopkinson rate, two charge or three charge; it all comes down in the end to the fact that you have three distinct charges to consider. First, because the man is on your line as a customer; second, a charge because he really forces you to keep a certain amount of equipment on hand to supply him with a varying demand; and third, because, if he chooses to take more and more energy, you have got to make and supply it.

Now, you will find if you analyze the conditions of supply, as some of us have done for many companies, that there is a comparatively small number of customers where it is exceedingly important that maximum demand be accurately measured. I was going over the affairs of a company not long ago and found, for example, that ninety-five or ninety-six per cent of the customers took seventeen per cent of the energy that was given out. When you bring in diversity factors you find under analysis that there is a large number of customers to whom the customer charge is by all means the most important. If you wanted to get that customer charge out of them I might say that you could almost afford to give them their energy for nothing, it is such a small part of the increased cost of keeping that customer on your line.

Therefore, if you are going to give a maximum demand meter to every possible customer, as some people believe ought to be done, and bring out his maximum demand and try to figure it, you are going to increase this customer charge which is so hard to get. The cost of the introduction of a new meter includes testing for accuracy. Our public service commissions are requiring that all meters be kept within a certain accuracy, that is one of the troubles. It is recognized that they raise the customer charge and I believe we are working in the wrong direction. That a good maximum demand meter is badly needed, one that is cheap, and needs very little maintenance, is unquestioned. There is a lot of work for such a meter to do.

Now, the second feature is, that, after all, as a commercial matter, they are useless in many respects. I think you would be surprised to know the number of people who kick because the bill this month is larger than the one last month. Now then, you are going to have them compare demands every month and ask you to come around and explain the maximum demand feature. You can take this maximum demand theory and separate your operating expenses and your investment, and work in your diversity factors, and so on, and finally arrive at just what you ought to charge a customer on the basis of the figured profit. Then the first thing you meet is your municipal schedule for lights, there you cannot, for a variety of reasons, get what you ought to charge. That disturbs a lot of things, because if you are going to get the total profit you ought to have, it is obvious that you have got to get it out of some other class of business. Then the residents have to be considered from that standpoint of voters. That is the plain English of it. Perhaps you ought to get a 10 cent or a 12 cent maximum charge, but you cannot, and consequently your maximum demand feature is gone entirely.

The inference that perhaps in rate-making we do need a maximum demand meter for all customers in order to get a logical rate, I will grant as a technical matter and as a logical matter; but I say as a practical matter it is very questionable if we need anything of the sort, except for those customers wherein maximum demand is really a very serious factor, and for whom we can afford to install a meter and keep it in order. You know that if your maximum demand meter is out a certain per cent and you are actually charging from $2 to $10 per kw. demand, depending entirely upon what kind of demand it is, you can imagine what a little mistake will make on a monthly bill, if you are dealing with a maximum of a certain type. All of those difficulties come in, so I am contending tonight that this matter of rate making is hardly an engineering matter. It is very much of a commercial matter, and I should be very sorry to see us go away with the idea that the ultimate end of all rate making is a maximum demand meter installed on the premises of every customer.

Edward J. Cheney: For ordinary residence business, and for much of the commercial lighting and power business as well, we have not yet come to the point where we can make up a rate schedule sufficiently complete to take in all of the factors which theoretically enter into the cost of service.

We necessarily have to neglect those which are less important. For the great bulk of business, in numbers of consumers, not in total sales, the demand cost is considerably smaller than the consumer cost; but even if we assume that we do want to make a rate schedule that follows the theoretical cost curve, how much would we be helped by having a demand meter in ordinary residence installations? Will the demand that we measure be the demand that affects our production costs? Certainly

not, if the peak on the station occurs during the lighting hours and, as we hope will soon be the case, consumers put in apparatus which at other times of the day for heating, cooking and power purposes will take more current than the lighting load.

The maximum demand instrument would record that large block taken during the daytime, which we are glad to furnish the consumer without penalizing him It would not catch the demand put upon the peak at the time when it is really serious. This point becomes more important as the efficiency of lighting goes up, so that for lighting the power required becomes less, while the use of electricity for other purposes increases.

Then there is another thing. I do not see how we could expect to read such a meter oftener than once a month, and it would necessarily record the highest demand made during the month. Almost every consumer will at some one time during the month make a large use of his installation; there may be a party at his house, but on that night the neighbors will be at his house and will use no current at their own houses. The station will not suffer by reason of that peak, and why should the man be penalized in his whole month's bill because on the one night he used all of his lights for a little while, whereas the average for the month was not excessive?

We have a good deal of trouble in justifying rates; I perhaps should not say in justifying them, but in making them seem reasonable to the consumers, and I am quite sure it would not seem reasonable to a consumer to have his whole monthly bill fixed by what he happened to do for one evening.

Philander Betts: The most complete study of rates that I have made was about two years ago in connection with the rates of a water company. To show the difficulty in trying to put in effect a logically and theoretically correct schedule, I would explain that the whole matter came up because of a complaint against minimum charges. The customers objected to payment of a minimum charge, for which they received something, and they certainly would not agree to pay a demand charge, for which they considered they received nothing. We recognized the correctness of the theory, of course, but the difficulty came in its application.

Mr. McClellan has emphasized the idea that rate making, or at least the application of rates, is largely commercial. I take exception to that to this extent: The application of the rates may be a commercial proposition, but I think the people who formulate the rates ought to be primarily engineers and understand costs.

Some of the worst complaints that we have had to deal with in New Jersey have arisen because the rate schedules and their applications had been made up entirely by people who did not understand the costs, excepting from the commercial man's standpoint.

I do agree with Mr. McClellan in this, and that is that the greater proportion of customers use so little energy in total kw-hr. that the customer cost, that is that part of the costs which are proportioned to the number of customers, is a very large proportion of the total cost of service. This being the case, we ought to be very careful how we increase that element of cost.

The addition of another meter, or the use of a meter which costs more than the present meters, of course increases the customer cost. Anything that involves an increase in the cost of meter reading, recording, billing, and so on, increases the cost. Indirectly there is another increase. One of the things which takes considerable time in the commercial office, along about the 10th of the month in almost every electric light office, is explaining to numerous customers just what a bill means. If that bill is made out for a certain number of kilowatt-hours at a certain straight rate, say ten cents a kilowatt-hour, there is very little to be explained, except to explain to the customer how it came that he used that number of kilowatt-hours. On the other hand, a rate that starts off by charging for the first certain number of kilowatt-hours, ten cents, and then eight cents for a certain number and so on--that kind of schedule certainly takes more of the time of the clerks in the commercial office, than the simpler form.

When it comes down to the application to a great number of customers of a complicated schedule of rates, although theoretically correct, it is very difficulty to explain to the great majority just what it all means.

I have been impressed with the necessity for one more thing in connection with getting the maximum demand, and that is to ascertain the time of its occurrence.

To go back to the question of the proportion of the customers concerning whose maximum demand we ought to have knowledge, and in connection with whose bills we ought to apply a theoretically correct schedule, I would venture the opinion that it ought to be applied to all customers where the average monthly bill is say greater than five times the minimum charge. Now, I think that if that idea were taken as a basis for further investigation that it would be found it would pay to apply a better schedule of rates than we have, to those customers whose ordinary monthly bills under present conditions are more than five times the customary charge.

What we need to know in connection with those customers to whom we ought to apply a schedule of rates which takes account of the maximum demand, is when the maximum demand occurs with reference to the peak load on the plant. It is easily seen that if the maximum demand of any customer occurs during the day t'me, even with a load curve exactly similar to that of another customer where the maximum demand occurs coincident with the lighting peak, that we do not

need to apply the same demand charge. A customer who will use his service at times other than peak times, with many companies, gets a special considera ion. A number of companies that I am familiar with have schedules under which the customers agree to absolutely disconnect their service before certa n hours in the day, and certain months in the year.

If we could have the time of the maximum demand properly shown, it would be a very simple matter then to apply to the demand charge a certain percentage representing the relation between the time of that maximum demand and the time of peak load on the plant. This would result in greater justice, and also in building up the business in a better way. We all know that these theories can easily be applied to large customers.

I was speaking tonight with a representative of a company which supplies hardly any customers whose demands are under 50 h.p., and in connection with that company probably every one of the customers pays enough to warrant the installation of a graphic meter. It is the customers whose bills range from $10 upward that we ought to cultivate in such a way as to induce them to use a larger number of kilowatt-hours at a time when the cost to the company is smaller.

John W. Lieb: The general statement in the paper that it is important to know the load factor in order to formulate a proper rate for rendering an electric service, may be conceded. That it is necessary for the rate so formulated to contain the load factor as a stated element in the actual expression of the rate in order that it may be deemed logical, is to say the least, open to question.

For instance, the fact that the charging of a storage battery requires under normal conditions some six or eight hours' use of the capacity with a resulting fairly definite load factor would seem to lay a proper basis, outside of or in addition to other service conditions, for the establishment of a class rate for that particular service; it does not follow, however, that the rate so established shall necessarily be expressed or stated in terms of that load factor; the mere statement that the rate is for the charging of storage batteries affords a reasonable and proper classification based on the essential character of that class of service, and the load factor may, therefore, be properly assumed as implied in the class rate without specific expression.

This is the case with many of the class rates of electric companies, where, in the calculations on which the class rates may be based, a certain average load factor is assumed as applicable to the class, but once the classification has been established, the load factor thereupon disappears as a numerical value or active factor. In such cases it may be useful and desirable, or even important, to know the maximum demand (from which the load factor may be calculated) but it is not necessary that the demand be known and used as a factor for each individual consumer in order that the rate to him may be logical or proper.

It may be true that the individual case may depart somewhat from the average assumed for the class as a whole, but such a variation should no more invalidate the general basis of the rate than the case where with identical annual load factors one consumer uses all of his current in two or three months, wh le another spreads his demand uniformly over the whole year.

While we know that in the operation of our street car systems the length of the ride has at least as great an effect on the cost of transporting passengers as the load factor may have on the cost of serving an electric lighting customer, yet we prefer in the former case to base our rate of fare fundamentally on the cost of the average length of ride of all passengers and not individually on the length of haul of each passenger. On this basis we shall soon be enjoying in this city a ride all the way from Coney Island to Mt. Vernon, a distance of about twenty-five miles, for the single universal fare of a nickel. The force of this may perhaps be better appreciated when we point out that it is generally understood that in this city any passenger who travels over 4 to $4\frac{1}{2}$ miles is carried at a loss. So in our rate making, even though the basis may not be theoretically perfect, it makes for simplicity to base our classifications on average group conditions of load factor, diversity factor, etc., and not on the characteristics of each individual customer, thereby avoiding serious complications in the formulation of the rate and in the method of the practical application to the individual case.

The author suggests that the change in the character of the residential load, brought about by the use of heating and cooking appliances, may involve a modification in the rate scale for residences. This may be perfectly true, but it by no means follows that the solution lies in the addition to the service equipment of a maximum demand meter. In fact, I believe quite the opposite is the case. A much more obvious solution is found in the establishment, where desirable, of a low secondary or tertiary rate, such as is used by the "point 5" group in England, where all current in excess of a certain quantity is sold at ha' penny per unit, to make it attractive for heating and cooking purposes.

The use of the maximum demand alone as a factor in the rate does not by any means make it theoretically perfect, for the time at which the demand occurs may be of even more importance than the amount of the demand, as far as the cost of rendering the service is concerned.

I beg to disagree with the author in the statements to the effect: " In order to render to a customer a logical bill for electrical service, there is required more information than is given by a watt-hour meter, " and again, " There is no better evidence of this than the fact that rates based on the kilowatt-hour alone are becoming more and more scarce." In my

opinion, the author has not, in any facts he has given us, laid the basis for either of these conclusions.

For us to agree with the author's contentions that residential rates which consider as an element in computing the rates the number of rooms illuminated, or their character, or their area, or the cubic contents of the space illuminated, or the number of outlets, results as the author says, "in a more just rate than the use of kilowatt-hours alone," requires something more than the bare statement of the author's opinion to that effect.

Much may .be said of the theoretical imperfection of the kw-hr. rate, treated rather cavalierly by the author, but it has one appealing, outstanding advantage of the utmost value in the actual conduct of the electric lighting business, and that is its understandable simplicity.

Now, we must admit that the maximum demand meter is a very useful instrument indeed, and capable, with advantage, of a wide use,—a much broader application, no doubt, than it has heretofore received,—but the proper field of its application can hardly be the class of residential consumers to which the author has devoted so much of his attention.

Many of these are served now at a loss under any practicable rate, and very many of them—in fact, the vast majority of them—are served at relatively low maximum rates, for which there is such an insistent demand from the public, but which entail a direct loss to the supplying company.

A few years ago a tabulation was made, by one of the largest companies, having at the time approximately 100,000 customers of all classes on its books, of the revenue derived from various groups of customers. It was found that 10,000 customers received bills averaging less than 65 cents a month; 28,000 customers received bills averaging less than $1.50 a month and 40,000 customers, or 40 per cent of all the customers served by the company, received bills averaging less than $2.50 a month.

To add another service instrument, in addition to the standard watt-hour meter, with its added incidental fixed charges and further maintenance, repairs, indexing, etc., does not appear to me to be a forward step in the direction of solving this problem. When we add the additional complications resulting from its use as a factor in the rate, in making out the bill and then in the customer's understanding of it all, it would appear that some simpler solution must be found—admitting the insufficiency of our present residential rate systems—than the application of the device for which the author has furnished us an interesting theoretical study.

What we need in our rate making is greater simplicity, not additional complication; lessened, not increased, cost of connecting each new customer; and a reduced, not an augmented, so-called "customer cost" in order that it may be practicable to gradually lower our maximum rates without increasing our losses from the residential class of business, so that we may extend the advantages of this beneficent agent of civilization.

H. G. Stott: I believe the fundamental basis of all rates is the cost of making the article. It does not matter what we add on to it later, the fundamental basis must be the cost.

The cost of making power is perhaps one of the most complex subjects of which we can take hold. Just take for instance during the hours of the day, early in the morning there is probably only about six or eight per cent of the plant doing useful work. If we applied the real cost of furnishing power to an all, night customer, we would probably have a charge of a dollar a kw-hr., if we spread it over fixed charges. However, that is entirely impractical, so that we must start off with averaging the cost at least for twenty-four hours; then averaging the cost over a longer period, as we cannot render bills each day; then averaging for each customer; then adapting the average to all customers of the same type, so that the monthly bill in itself becomes the bill of a large number, and furnishes the average cost as at present given.

I do not think that Mr. Lincoln really meant in his paper to apply the maximum demand indicator to small customers, such as those who receive power for lighting houses; but it seems to me that we can classify it just about the same as Mr. Lieb did the subway. You go a certain distance at a flat rate of a nickel; but I have yet to hear of the trolley company that is ready to take me to Buffalo, or San Francisco, or any other place. There you get into the wholesale business. I think we will find those two classes distinct, the retail and the wholesale. We are pretty thoroughly familiar with the retail. The wholesale customer must be treated independently of the retail customer. There, I think, is a very distinct field for the meter described by Mr. Lincoln.

The cost of power, as you know, is a very complex subject. It is made up of what we might call, first, operating charges, which follow approximately a flat line, or a very level curve. For short periods of time, such as one hour, the fixed charges are perhaps three or four times greater than the operating charges. As the time goes on and as the load factor becomes greater, or nearer one hundred per cent, the fixed charges become relatively negligible, whereas the operating expenses are really the important sum.

It is quite obvious that we must, at least for wholesale customers, have some means of determining maximum charge. I therefore feel that there is a very distinct field, a legitimate one, based upon the real cost of power, for such a system for wholesale customers.

C. I. Hall: I believe that discussion of the various functions of the instrument will be illuminative. Mr. Lincoln's very clear and concise discussion of the proposed device has led me to the belief that he has possibly overlooked the basic principle of a demand indicator, which is now safely established as a commercial product.

He makes the statement: "Other indicators of the same general

type of Wright's have been recently announced, but not enough experience has yet been obtained with them to determine their general sufficiency."

The Type H demand indicator is a differential thermometer constructed primarily as a lagged indicating ammeter, but capable of wide modification in its application and use. There is no new element in the idea of a differential thermometric principle used as a measuring device, but the point of novelty in the Type H demand indicator lies entirely in its time deflection curve and the method of obtaining such a curve. As pointed out so clearly in the paper under discussion, the characteristics of the Wright demand indicator are not of the highest order obtainable; that is, the rate of deflection in the first few minutes of load is extremely rapid, while that during the remainder of the time interval is slow. The problem before the designer was, therefore, to construct a device which would approach as nearly as possible the straight line characteristic which Mr. Lincoln has pointed out as being ideal.

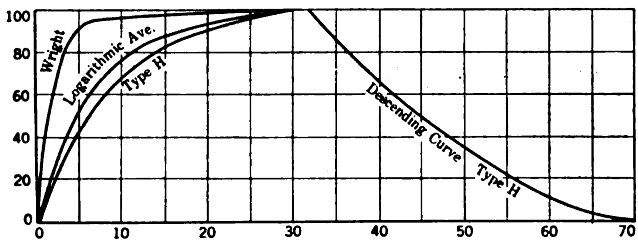


FIG. 1—COMPARISON OF CURVE OF TYPE H AND LOGARITHMIC AVERAGE CURVE

The first experimental device constructed depended entirely upon the principle of thermal storage; that is, the measuring element was heated not directly by the heating element, but indirectly through a thermal storage volume practically proportional to the time interval desired. It was found that this corrected the curve to a large extent, but that it still was rather far from the ideal desired. The curve obtained was what Mr. Lincoln has so aptly christened the "logarithmic average."

Further development led to the adoption of a second thermal principal, that of heat flow along conductors, which has very materially assisted in obtaining the desirable time constant inherent in the Type H as manufactured today. Instead of allowing all of the heat developed by the flow of energy to act upon the entire measuring element, this device through the use of a spiral thermostatic spring gives a lower deflection during the early part of the time interval than would the uncompensated device.

Fig. 1 shows the characteristics of the three indicators. I have shown in the curve labeled "Wright" the characteristic curve that you are all probably familiar with, the Wright demand

indicator, which is uncompensated. I have drawn in the intermediate curve the logarithmic average, so christened by Mr. Lincoln, taken from one of the curves given in the paper; and, third, the characteristic curve of the Type H demand indicator. As I stated before, the characteristic of the Type H, without a heat flow compensation, would be coincident with the logarithmic average curve, but due to the fact that that does not approach very closely to the desired straight line characteristic, an additional compensation was introduced, which, as you see, did improve rather materially the form of curve obtained. I should like to illustrate rather carefully the use of the heat flow idea which was employed in connection with the Type H. Fig. 2 illustrates one of the operating elements of the Type H demand indicator, consisting of the spiral thermostatic spring A, the stud *B*, which mounts the thermostatic spring and the heating element, and the heating element itself, *C*.

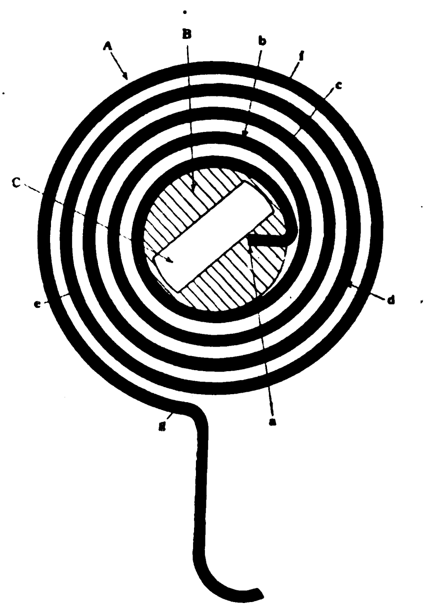


Fig. 2

It will be noted that heat generated within the heating element *C* must be transferred from the element to the stud *B* and thence to the spring *A*. It will also be noted that the spring *A* is connected to the stud at one point only—the innermost. The additional compensation, that is, a compensation additional to the thermal storage idea, is obtained by the construction as illustrated. As the temperature of the stud *B* gradually rises, on account of the current flow, the temperature of the inner end of the thermostatic spring increases, thus creating a temperature gradient from the point *a* to the point *f*. Such difference of thermal potential causes heat to flow in the conductor from *A* around the spiral toward the other end of the spring. If the spring is so proportioned in length, section and ratio of radiating area to volume that the increase of temperature reaches the point *b* in the first five minutes, *c* in 10 minutes, *d* in 15 minutes, etc., then at the end of 30 minutes the entire thermostatic spring will be increased to its maximum temperature. With such a condition it is obvious that the deflection of the thermostatic spring during the first five minutes when approximately $\frac{1}{6}$ of the thermostatic metal has been subjected to the increased temperature, will be

materially less than it would have been if the entire thermostatic spring had been heated up to the temperature of the section from *a* to *b*. It is thus obvious that the time deflection curve of the Type H must at all points lie below the curve of a device using heat storage alone, and, therefore, must approach more nearly a straight line, as illustrated in Fig. 1.

I was particularly interested in the cause to which is ascribed the unreliability of the indication of the Wright demand indicator; that is, the varying sizes and thermal capacities of the leads, with which the device is connected in circuit. In order to test out this possible variation in connection with the Type H demand indicator, a test was made, using first No. 14 rubber-covered wire, and, second, ½-inch bare copper rod, which I believe is the extreme in possible connecting wires. Under such conditions, a variation of slightly less than one per cent was obtained.

I wish also to point out that perhaps Mr. Lincoln has overlooked one other point, the change in the volume of the measuring liquid within the Wright demand meter. I believe that careful investigation will show that a very large portion of the unreliability that he speaks of is caused by a change in the volume of the measuring liquid rather than in the variable thermal conduc ivity of the leads which connect the Wright demand meter in circuit.

Mr. Lincoln has called attention o what he considers an inheren defect in demand indicators operating upon a definite time interval basis. He has presupposed a very heavy demand made upon the service exactly at the mid-point between two demand periods and ceasing at the mid-point between he next two demand periods. This, of course, must be onside ed as a very special condition and not usual on the type of loads on which demand indicators are employed. However, granting such a possibility, I still cannot agree that this is an inherent defect. There is, of course, one demand of the month which is the extreme maximum, but there are also a grea many more which are substantially the same. I has been granted by rate experts that what they wish to determine in the demand measurement is the average conditions, and although the device may not record the extreme maximum, yet it will give a record substantially equivalent to his and pe haps form a better basis of billing as being more representative o the average value.

The e are, of course, pecial cond tions under which prac ical y any existing form o demand indicator will not give a correct ind cation, and under such conditions it is obvious that a demand indicator operating upon a principl which doe no make it appl cable to that load condition should not be used.

In this connection, it might be well to point out what I on ider a very much more erious defect in a device mentioned by Mr. Lincoln in he following words: " In still another type, the time of response of an indicating wattmeter of the usual induction type is delayed and regulated by an associated integrating watt-

meter. This type gives greater promise than anything heretofore suggested."

There are two load conditions under which the operation of the device mentioned is extremely erratic, in one case giving practically no indication and in the other case giving a demand higher than the average In order to illustrate the effect of such condit ons, I have assumed the load which gives the maximum possible error. First, a load which is thrown upon the circuit from 10 seconds to one minute, is off for approximately the same time, and again comes on, repeating itself indefin tely. This would be a characteristic load of a rolling m ll, an electric welder, hoist, elevator, etc.

Due to the fact that only the advance of the pointer of the device mentioned is retarded by the watt-hour meter, (the return from an indication to 0 being instantaneous), the action of the pointer would be to rise slightly during the low portion, return to 0, rise slightly in the next load portion, and so on. It is obvious that under this condition practically no demand will be indicated, while the true average should be approximately one-half the instantaneous maximum.

The second condition may be shown more clearly by a load of constant value imposed for the time interval, (so that the pointer arrives at its final setting), and then a doubling of that load for one-half the time interval. Under such conditions, the device will indicate the full load imposed in one-half the time interval. Broadly stated, then, the time interval is a variable amount, depending upon the previous history of the load. In the case cited above, the time interval error is of course exaggerated, but the fact remains that upon variable loads of any sort the time interval will be proportionately variable. Because of the two conditions, one of extreme under-registration, and the other of over-registration, I feel that Mr. Lincoln's statement, "and the device gives greater promise than anything heretofore suggested," is subject to further consideration.

Mr. Lincoln points out that one of the undesirable features of the Wright demand indicator lies in the use of liquids and glass tubes. It seems to me that in the device in which he proposes using copper bellows and kerosene he has not approached more closely a commercially practicable device.

I am rather confused by the stress laid upon the fact that the proposed device records directly in kilowatts when taken in combination with the statement, " another point in favor of the ' logarithmic average ' is that the heating of generators, cables, transformers and other electrical apparatus fol.ows close y the same kind of law. Therefore, when we are approaching the limit due to heating, a " demand based on a logarithmic average is much more logical than one based on the commonly accepted form of average."

I should like to point out that at the present time the heating of generators, cables, transformers, and other electrical apparatus

is not proportional to kilowatts, but substantially proportional to the second power of the current. If the statement quoted, there ore, is correct, it would appear that an ampere record would be more desirable than one in kilowatts.

The description of characteristics of the proposed demand indicator have been confined entirely to its ascending curves, and no mention has been made of the form of the descending curves. This, I wish to point out, is practically as important as the ascending when variable loads are considered, as the final indication of the device depends not only upon the rate of advance, but upon the rate of return upon a reduction of load.

J. B. Taylor: Personally, I feel that the expression "a theoretically correct rate," which is often used and has been used a number of times this evening, is far beyond the conception of any commercial man or any engineer. To take on one thing like the maximum demand as knowing that to be the complete desirable factor for the equitable and the desirable rendering of bills, is to say the least absurd; because the time at which it occurs, the power factor, the position of the customer on the line, the position of the customer with relation to other customers, the relation of the load to the size of his transformer, the drop in the load, his relative position to the load, etc., are all factors which cannot be neglected if any one is concerned with making what he conceives to be a theoretically correct rate. The result of this endeavor to establish a theoretically correct rate based on one or two of what may seem to be the more obvious factors outside of the definite flat rate, would seem to me to curtail the use of the very products which the whole enterprise is established to sell.

The maximum demand indicator as described, is of course a highly desirable device in general testing, in determining whether an individual customer is perhaps overloading his transformers or wires, this of course referring usually to the small customer; but I cannot see how you will receive any benefit except in the case of those customers whose possible demand is so great that they may cripple the system: If the system were capable of delivering 3000 or 4000 kw. and a single customer came on with a thousand or so, he is in a peculiar position as regards the plant as a whole, and special rates may properly be devised for him; but with three or four thousand small customers it is hard to see how any one of these, taking even ten or twenty or a hundred times his normal load, can do anything other than swell the rates of the company. That makes it difficult for me to see why so much stress is laid upon the maximum demand of the customer who, to repeat, is so small that singly his load and overload cannot be felt at the central station. Of course it would be different if all these small customers were in the habit of taking their loads at the peak hour; but if that were the case it would have been learned very early in the game, and the maximum demand determined just as readily at the central

station as otherwise. It certainly is inconsistent for the lighting company to make a rate which gives a lower price per kilowatt-hour after a certain number of kilowatt-hours have been used in the month, and then expect to put on the maximum demand indicator, which puts on an excess rate, if this greater amount of current which apparently they desire to sell is used in two or three small bites.

William McClellan: Constant reference has been made to the fact that it is important to know the time of the load curve at which the maximum demand occurs. Of course, I agree with that, but there is one point that I think is being overlooked: When you are talking that way you are talking entirely on a so-called cost theory. I do not think it can be assumed that the value of service theory has entirely disappeared from our rate making. As a matter of fact, the man who makes a kilowatt demand ought to be expected to pay just as much for it whether he takes it on or off the peak, although it is true that if he increases that peak he increases your total cost of rendering service. There is such a thing as a value of service theory that I do not think is entirely apart from rate making. One of the hardest things we have to do in reference to these complex rates, is to make a man understand why if some other consumer just keeps off the peak he can get a lower rate. We explain to him very carefully that it is being off peak that reduces his service bill; but he looks at it from the point of view of the value of service. He says, " I get a kilowatt; so does he. He makes use of it, so do I. It is not of more use to either one of us than to the other." As a matter of fact we do not do much of that, except to those that we cannot get in any other way. Of course that lower rate is an inducement to get everybody to work off peak. Then, you cannot get your city arc lighting contract except by surrendering something; your wholesale rate for residences may be way down and then you may have a great big competitive block that you cannot get in any other way than making a rate which will induce a man to cut out his steam engine. Those cases are absolutely fixed; while in another community there is a number of consumers to whom service is extremely valuable. If you have got to have a certain tariff in order to stay in business it is not hard to see who is going to pay the bill on the value of service theory. That is a distinction that has got to be taken into consideration, and I think after all is a fundamental reason why we cannot adhere to cost theories of making rates. We must get a set of rates upon which we can do business and live.

H. W. Peck: For years central station men in their commercial discussions of rate making have besought the manufacturers to develop a good maximum demand meter. We have not told them or indicated that we wanted such a meter for every customer upon our lines, but we have undoubtedly wanted such a meter.

I simply want to indicate that we still want such a meter, and I hope that Mr. Lincoln will continue the development of his meter and that Mr. Hall will give us further information regarding the Type H meter, and that other good meters will be presented and developed for our use. We want them perhaps for fifteen or twenty-five per cent of our customers, and not for the seventy-five per cent of our residence customers.

Mr. Harold: In Mr. Lincoln's paper the statement is made: "It may be shown that this device constitutes a true thermal wattmeter and that its indications are always proportional to watts, whether the circuit is direct current or alternating current."

The statement as to direct current on a device employing a transformer does not appear exactly rational. It would apparently be necessary to introduce a rotating device if direct current were used.

I suppose that the error is probably in the statement "that this device"; the theory holds rather than the device.

Walter N. Polakov: The influence of the demand rate and other corrections to the common kw-hr. measurement of power consumption is but a small portion of the problem of rate making.

While it is of importance to know what is the maximum demand, load, power factor, etc., of each particular consumer, this does not represent what capacity of central station equipment shall be reserved for this particular customer. The diversity factor makes the maximum demand imposed on the central station only a fraction of the arithmetical sum of maximum demands of all its customers. In my opinion it is the duty of the new business or commercial department to find out how to reach such classes of customers as to keep the station load uniform and load factor high.

If this problem is properly solved, and Mr. Lincoln's instrument does not help its solution, the portion of idle (spare) equipment in the plant is materially reduced and expenses of not operating this portion of the plant will be turned into dividend-making investment.

Three elements constituting the basis for the determination of rates for various classes of customers are:

1—cost of current
2—cost of delivery of the current
3—cost of other services required.

It is quite evident that no demand indicator could throw any light on the correct determination of the value of the three last elements of the rates.

I fail to see why the consumers should be penalized for the company's inability or neglect to secure for the power plant more uniform load, balancing up the individual peaks. Neither do I see sufficient reason why the rate maker should neglect the second element, the charge for the use of equipment through which the given customer is served. Those served through under-

ground conduits should have a higher rate than those fed directly from overhead high-tension transmission. Similarly, the maximum rate of demand determining capacities of feeders and transformers assigned to a certain customer should affect only this part of the total rate. On the other hand, the third element of rate, namely, prorated general business expenses such as supervision, meter reading, billing, etc., remains practically constant per customer whether his peaks are heavy or not, whether his bill is 35 cents or $35.00 per month.

In other words, demand indicators or any modification of this class of instruments, neither make the reason for certain charges clearer to the customer, nor do they affect the most important part of service cost. The fact that many researches are being made in this direction indicate, to my mind, a need not for an instrument but for a revision of prevalent methods of rate making.

T. I. Jones: In any analysis of the proper form of rates in connection with the cost of supplying electric service, it must be borne in mind that the principal object of all rates is to get the business—I may add, to get the business at a profit—and any form of rate, be it ever so exact from a theoretical standpoint, that is not conducive to this end, fails of its purpose.

Rates, to be satisfactory, must be simple, easily understood and comprehensible to the layman, who knows little or nothing about the technical side of the question. Particularly is this true of the smaller customer.

Mr. Lincoln, in his paper, states: " When the central station supplies electric service to a private residence, it is justified in establishing a rate for that service which is based upon a reasonably accurate knowledge of the average load factor that will obtain therein."

Now, as a matter of fact, if we come to consider and analyze the cost of service to the average private residence or apartment, we will find that load factor is one of the least important items of cost. When you consider that there are in one company which I have in mind, over 20,000 residence customers whose monthly bills are less than $1.00 per month each, you will realize what I mean.

As a matter of fact, perhaps the greatest element of cost to the average residence customer is what we may term the customer's charge—the cost of service, reading the meter, the making of bills, and the auditing and collection of accounts. Before the supply of current at all, these items make up a part of the fixed charge of a customer's service, which in all of the smaller residences form the greater part of the cost of the supplying company.

The kw-hr. charge, too, is in such cases almost a minor element in the total cost of service. Especially is this true when one appreciates the type of lamps now used with residence bills of $1.00 and less and then considers what these bills will be as the

efficiency of lamps is improved upon. The kw-hr. consumption, then, will become less and less, and those companies who have not a minimum guarantee or a customer's charge aside from the matter of kw-hr. consumption, will find the number of unprofitable customers increasing at an alarming rate.

Then, too, the private residence consumer, who is now using more and more heating and cooking apparatus, oft times in the greater majority of cases, will use this apparatus at a time when it is very much off of the peak of the central station. Should he be penalized then by a rate which would measure his demand on the off-peak use of such a device?

Mr. Lincoln also states: "The modern rate-maker has long since recognized the fact that the information given by the simple watt-hour meter is not sufficient to enable him to render a logical bill and by some makeshift he has endeavored to take the maximum demand into account without directly measuring it."

It is quite true that the mere kilowatt-hour charge of the customer, as before pointed out, is not all that should be included in the logical bill, but as a matter of fact, neither is the maximum demand with the kw-hr. rate sufficient in the large majority of cases of residence customers. So where the maximum demand is as unimportant as it is in residence service, why go to the expense of measuring it when for all intents and purposes it can be estimated satisfactorily in its own unimportant ro e?

What Mr. L ncoln has to say on the general subject of measuring o maximum demand applies more generally o the commercial customer, wherein the time of maximum demand is unimportant, but we soon come to another customer in the question of the consideration of the use of the maximum demand meter.

Many companies base their rates for selling power on various widths of maximum demand. It must, of course, be considered that a maximum demand having a time interval of thirty minutes would be materially different from a maximum demand having a time interval of fifteen minutes, and any device which is constructed on a basis of definite time interval must give consideration to whether or not the time interval is such as the company using such a device has already adopted in its maximum demand rate schedule.

On business of excessive demands on the system, such as in hoisting or intermittent loads, a demand interval of five minutes is not excessive, while on the average even running of a central station business five minutes would be much too small. On railroad work the generally conceded width of maximum demand is one hour. These are things that must be considered in the use of a maximum demand indicator.

Then, too, in many of our largest industries the labor schedule may be so arranged as to bring the maximum demand of the power used, off of the central station peak. Here the time at which the demand occurs is an important factor, and this element must be considered in making what is known to the central

station manager as an off-peak rate. In fact some of the largest business of the central stations today is based upon rates wherein the demand is far removed from the demand of the central station. In such cases the demand charge is materially reduced in the customer's bill.

There is, however, need, and a vital need, for a first class maximum demand indicator, cheap, compact and accurate, and any study along those lines will be welcomed by the central station industry as a whole.

A. W. Burke: The commercial men would like to have a rate based on the maximum demand of load factor curve and then like to interpret that rate and administer it to satisfy themselves in order to get the business; and I quite agree with them, that is what you have got to do to get the business.

The question of a maximum demand came up recently, and it was finally decided that we should have a maximum demand contract. After a lot of work a maximum demand contract was prepared. It was based on the hour's use of the connected load, and all the other things that go into it. When we came to apply that contract we found a certain number of people were willing to accept it. Others were not, because they were not sure that this maximum demand charge was just. Difficulties arose when it came to the question of obtaining a satisfactory maximum demand meter. I found that they had maximum demand meters abroad, but had got tired of them and had adopted a new device which they had termed the excess watt-hour meter. This is a sort of compromise, or you might call it a substitute for the maximum demand meter. Instead of selling you at your actual maximum demand, they will contract to sell you so much power. For instance, we will say 10 kw. and you will have a sliding scale covering all the power you can use without exceeding 10 kw. demand. For all the power that you use in excess you will have another rate. The excess watt-hour meter is the instrument which determines between the amount of power taken at the lower rate of consumption and the amount of power taken at the greater rate. At that time such instruments were not available in this country. I wished to try the scheme and see if there was anything in it. We have done so, and have been successfully working such an instrument of a makeshift design, for the last year. If a customer does not want us to put a maximum demand meter in, we will sell them on an excess basis, and we find that the majority of them want to buy on an excess basis.

We find from the actual results in placing the demand meter alongside the excess meter that we have arrived at practically the same thing, and we have got a customer that understands his rates. He understands that if he keeps below the fixed maximum he will have a very low rate, but for every second that he exceeds that amount he is paying a penalty.

Such a rate has been successful in Europe. There were, just

before the war, five manufacturing companies making these meters, which would indicate it might be a satisfactory compromise. We have found it to be a successful means of dealing with the maximum demand question.

F. T. Leilich (by letter): On the assumption that the loss of heat from a mass follows a straight line law, which as pointed out is practically true for relatively small temperature elevation, Mr. Lincoln writes the following equation (Appendix 1).

$$SET_1\, dt = SE\theta\, dt + M\, d\theta \qquad \textbf{(1)}$$

This may be written:

$$SET_1 = SE\theta + M\, d\theta/dt \qquad \textbf{(2)}$$

It is interesting to note that this equation is similar to and of the same form (linear differential equation) as the well-known equation for the e. m. f. applied to a circuit containing resistance, R, and inductance, L; that is:

$$E = Ri + L\, di/dt \qquad \textbf{(3)}$$

(**2**) and (**3**) are readily solved by separating the variables and integrating. As $\theta = 0$ when $t = 0$ the constant of integration of(**2**) is determined and the solution found to be:

$$\theta = T_1\,(1 - e^{-SEt/M}) \qquad \textbf{(4)}$$

The solution of (**3**) is:

$$i = E/R\,(1 - e^{Rt/L}) \qquad \textbf{(5)}$$

The rate of increase of the current of (5) is di/dt, and

$$di/dt = E/L\,(e^{-Rt/L}) \qquad \textbf{(6)}$$

When $t = 0$ $di/dt = E/L$ which is the initial rate of increase of the current. If the current continued to increase at this rate the time to attain its final value, E/R, would be; $t = E/R \div E/L = L/R$. Substituting L/R for t in (**5**) we find; $i = .632\ E/R$, that is, 63.2 per cent of the final value. The value of L/R, the time constant of the electric circuit corresponds to M/SE, which may be termed the thermal constant of the mass under consideration. Just as the time constant of the electric circuit may be changed by altering the value of L or R so may the thermal constant, or the time for a mass to reach 63.2 per cent of its final temperature, be changed by varying M or SE.

R. S. Hale (by letter): Mr. Lincoln's paper does not take up the questions that are of chief interest in modern rate making.

In determining the proper rate to be made to give a supply

of electricity to different classes at the lowest prices, each rate must first include those costs which would be saved if that supply were not given, this being, in the case of electricity, the bare cost of production; that is, most of the coal and some of the labor for producing the kilowatt-hours, which would be saved if the particular supply were not given, and also interest and other fixed charges on such investment as would actually be saved if the particular supply were not given.

These costs are what are known as the increment costs and must of course be included in the rate whenever they are necessarily involved in the supply, but not otherwise.

Sometimes, as when two customers or rather when two classes of customers use the same investment at different times, there would be no saving in investment if the supply to one of these classes were given up: or in other words, the increment cost is entirely independent of the demand of *either* of these customers.

In addition to the increment costs which can and must be assigned to each class, there are in any company a large amount of unassignable costs, that is, costs which cannot be assigned or allotted to any particular class of customers or portion of the supply because they will not be reduced when any single class of customers is not supplied.

The best example of this is the organization cost, as an expense which will not be increased afterwards no matter what classes of customers are taken on. If any new class of customers will pay any portion, no matter how small, of this expense, the amount that has to be collected from the other customers is thereby reduced.

A similar expense would be the cost of poles, which cost would be the same (up to a certain limit) no matter whether much or little electricity is supplied over the wires that are carried by these poles, so that it cannot be assigned to any particular portion of the electricity, either in whole or in part, though of course this cost must be paid by some one.

The chief question in making electric rates is to divide up these unassignable costs so as to have the plant used most efficiently, and so that the rates for each class shall be as low as possible while still getting a fair return and no more than a fair return from the whole business. These unassignable costs may be divided among the business in various ways, one of which is in proportion to the demand.

The actual electrical demand and electrical load factor, while important in some cases, are only a part of the factors that enter into the question of making rates, because there are so many cases where the best and lowest rates are entirely independent of the electrical demand of the customer.

The first question is whether to use the actual electrical load factor as measured in different ways, or whether to use some other feature, as by making class rates or by using the number of rooms in a house or the connected load, etc. When it has

been decided for some cases to use the electrical demand, the question of which demand, that is, the minute or hour demand or the average of several readings, is of the next importance; and when this has been decided, the question of an instrument to measure it exactly, comes in.

Mr. Lincoln's instrument will undoubtedly be very valuable when the demand has to be determined, but I feel it necessary to bring out the fact that in many cases there is no call for determining demand in order to make the best and lowest rates.

E. J. Blake (by letter): In the discussion of Mr. Lincoln's paper much stress was laid on the commercial necessities of rate making, and particularly on the necessity for simplicity of rates. It seems to the writer that a matter of fully as great commercial importance was overlooked, namely the value of low rates per kilowatt-hour.

It is fair to assume that any added charges for demand, or customer expense, would be offset by a corresponding decrease in the kilowatt-hour rate; and the remarks of several gentlemen make it evident that this reduction could be very radical if the added charges were sufficient to cover the costs that they represent. Possibly something of the order of one cent would cover the added cost to the supply company for each kilowatt-hour consumed. A rate of anything like this amount, even though accompanied by a comparatively large service charge, ought to bring about a very marked increase in power sales and in load factors. It would tend to prolong the lighting hours and to increase the use of power for other purposes. For example, it would greatly change the economic status of electric refrigerators, and perhaps expand the field of electric cooking beyond the chafing dish and percolator to the every-day work of the kitchen.

As regards simplicity, the composite rate is not necessarily so impractical as some of the gentlemen would lead us to believe. The fact is that many of the rate schedules now in use are in reality veiled composite rates, in by no means the simplest possible form. For example, a stepped rate of ten, nine and eight cents according to the energy used, with a minimum charge of one dollar a month, is not easier to figure or to comprehend than a service charge of a dollar and a half with an added charge for energy at a uniform rate of two cents. In the latter case the service charge should include the customer expense and demand expense for the average small user. The addition of a demand charge for loads exceeding a fixed minimum would make the same schedule applicable to a considerable part of the larger users. It would add nothing to the expense of handling the small customers because the supply company would measure the demand only in those cases where the return justified the expense. Waiving the right to measure and charge for excess demand could hardly create dissatisfaction among the small consumers; and collecting the demand charge from

the larger consumers ought not to entail extraordinary difficulties when the customer was shown that his total rate per kilowatt-hour was less than his neighbor's rate in which no separate demand charge was included.

In some cases the composite rate would materially simplify the work of metering and billing. This would be true whenever the reduced energy charge made it possible to include in one schedule two services which had been separately metered and charged, such as lighting and small motors supplied from the same mains.

In the normal case it is to the interest of the supply company to get all the business that pays and no other business; in other words to get all the business that yields a profit over the cost of service. If the charges in every case could be accurately proportioned to the cost of service there would be no unprofitable business; and no business which could profitably be handled would be lost because of excessive rates. No one would contend that this ideal condition is attainable, but it does not by any means follow that we cannot establish thoroughly practical schedules that will approach it much more nearly than the flat energy rate or any of its common modifications. The flat energy rate implies pro-rating customer expense and plant expense on the energy consumed. The practical result among small consumers is that energy is loaded with several hundred per cent of charges which do not at all represent costs occasioned by the use of energy. The consumer who uses current twenty-four hours a day is penalized with an altogether disproportionate share of the general expense, while the short period user gets off with much less than the actual cost of his service.

Alexander Dow (by letter): It may be clear to Mr. Lincoln that the determination of the maximum demand of a customer, and the determination of the part of the demand costs of the supply system which that customer should pay, are two things and not one and the same thing. His remarks as to classification, indicate that he does recognize their difference, but the paper read as a whole must give a contrary impression to his hearers. He is right in his conclusion No. 2, that load factor must be recognized in some manner, but he is wrong in implying that the load factor obtained by correlation of the reading of a maximum demand indicator such as he has invented, with the reading of a watt-hour meter, is the measure of the cost of serving the customer, or of the proper price to be charged for the service. Mr. Lincoln says that when we come to consider the expense involved in obtaining all necessary information for rendering a logical bill, it may easily follow that proper classification is the preferable horn of the dilemma. I take it that he consents to a proper classification, with, for instance, such classes as industrial power and residential service. But I also take him to teach that within each such class the maximum demand of each customer, regard-

less of when or how it arises, measures the proportion to be paid by that customer of the demand costs chargeable to the class.

Let me say that I not only believe in, but have used for many years, rates in which the load factor is recognized. Ninety-five per cent of all the customers connected to the system which I manage are served under rates of either Wright or Hopkinson form. Let me say further that I have no prejudice against a maximum demand indicator. On the first of September there were 10,812 of these costly devices, of the Wright type, in service on that system; besides sundry and divers printographs and graphometers. All of these things have their place and use. None of them can justly distribute demand costs between different classes of customers. Neither can any of them distribute demand costs within any class unless that class be entirely composed of individuals having load curves of similar form.

Consider industrial power as a general class. A factory making men's clothing or overalls develops its maximum load five minutes after the whistle blows in the morning; carries it with hardly a flicker until noon; drops it for the noon hour to pick it up and carry it throughout the afternoon until quitting time; and one day will be exactly like another unless dull times cause operatives to be laid off, or exceptional orders call for overtime work. The load curve of a jobbing machine shop with a foundry annex is seldom the same on two successive days. On each day on which a melt is made there is a well-marked afternoon peak due to the blower supplying air to the cupola. Assume that the constant load of the clothing shop and the maximum load of the machine shop during the blast are equal to each other. Mr. Lincoln's demand indicator will assess the same demand costs against each customer. Now please consider the cost of serving these two customers. Beyond shadow of doubt the clothing factory requires that the central station install equipment for the indicated demand. That is to say the cost of service is, other things being equal, properly measured by the demand indicator. But the cost to serve the machine shop may or may not be properly measured by the demand indicator. If the central station is small—for example, if it has only these two power customers—it may be compelled to make the same investment for the one customer as for the other, but if it is a large central station serving many industrial customers, the cost of readiness to serve the machine shop will be greater than that corresponding to the average day load of the shop, but less than that corresponding to the maximum. The diversity factor of all the erratic loads of the metal working industries will result in their being served by a station and line capacity very much less than the sum of their individual demands. Whereas the capacity required for any number of clothing factories will be the sum of their individual demands.

Consider the relation of these two loads to the system, on the assumption that there is a peak due to evening lighting or to the

overlapping of evening lighting with the industrial load. Clothes making, textile mills, etc., superpose their requirements squarely upon the winter evening lighting peak. Metal working industries, almost without exception, taper off their demands during the last hours of the working day.

My study and experience of nearly twenty years in one of the industrial centers of the country have forced me to the conclusion that no single measurement of customers' demand will serve to properly distribute demand costs within the industrial power class. The method which has served best within that class is to plot load curves by half-hourly or hourly readings throughout a working day, at intervals of two or three months, and to take the average of not less than three readings as the basis of load factor ca'culations for rate making.

Now consider the special case of residential service, to which Mr. Lincoln devotes several paragraphs in his introduction. Lighting does not in every case constitute the bulk of service to a residential customer. What I take Mr. Lincoln to mean is that lighting fixes the maximum demand for the residential class, which is true. But the maximum demand of the individual is quite likely to be fixed by something other than his evening lighting. There are many cottages and small apartments using electric light whereof the connected lights require less than 600 watts—which means that a single 600-watt flatiron will make more of a demand than all the lights in the house. There are many other apartments, where the connection may exceed 600 watts, but the ordinary evening use is less. Will Mr. Lincoln undertake to collect from the ladies who preside over these cottages and miniature apartments, bills, rendered according to a reading representing the activities of Tuesday morning? If so, he is a bolder man than I. And if such bills were collectible would they be equitable? Would the Tuesday demand, off peak, be a proper basis for the allotment of demand costs against that customer? Or, to revert to the experience of Mr. Arthur Wright more than twenty years ago, would the extraordinary occasion of an entertainment, or of sudden sickness, causing the turning on simultaneously of all the lights and heating appliances in the house, be a proper occasion whereon to allocate demand costs against the joyful, or sorrowful, customer in question? Mr. Wright made a rule in Brighton that if a customer planned to give an entertainment he could, for a nominal fee, have the demand indicator switched out of the circuit for that evening. I don't think I was ever told how Mr. Wright dealt with the other stated occas on for unusual lighting. But I, having something like 100,000 residence customers to deal with, would hate to find myself requiring the production of a medical certificate as my protection against punishment for rebating.

The place for demand indicators is in commercial lighting: the lighting of stores, warehouses, etc., where each customer makes his maximum demand at the same time and where it is very important to give the long-hour customer the lower average

rate which he earns. In that class of service the load curve of one customer differs from the other, not at all as to the time of peak, only as to the height of peak and as to the continuance of the load or a part of the load into the later hours of the evening. As between customers in such a commercial lighting class, the demand costs may be properly apportioned by the readings of the demand indicators, and load factors comparable with one another can be arrived at by the correlation of these readings with the watt-hour meter readings Rates for commercial lighting made on that basis work well in practise, and have worked well in many cities and for many years. So likewise have residential service rates recognizing load factor worked well, where the demand charge has been based on something different from measured demand—even the illogical rateable value method is working very well in England—but no continuing success has been obtained anywhere with residential rates based on measured demand—nor do I think it can be obtained.

J. G. DeRemer (by letter): In determining the rate of return on the investment in a central station property, there is of course, among the various elements to be considered, the determination of profit. While the profit should be determined as a percentage earning on the total investment, it may quite satisfactorily be based upon the output of the property, provided a periodical adjustment is made to correct for improved load factors. In fact, it would seem only fair with such correction eliminated, inasmuch, as an improvement in load factor results from efficient administration and operation.

I have used the following method in establishing rates for the larger customers of a company operating in the business section of a large Western city and found it to give satisfactory results to the company as well as to the customer.

Let N = The maximum demand of the customer.

Let M = The maximum demand of the system.

Let X = The demand of the customer during the period of the system daily maximum demand. (See Fig. 3).

That is, X and M are coincident as to time.

The customer's demand charge does not depend so much upon his maximum demand, N, as it does upon X, the demand taken at the time of the system maximum demand. Hence, the customer should pay a demand charge proportional to $\frac{X}{M}$. Thus the demand charge $= \frac{X}{M} \times$ fixed costs per kw. maximum system demand, or plant investment. That is, if the fixed charges of the system be considered as consisting of

Constant operating cost	$= O$
Interest	$= I$
Depreciation	$= D$
Profit	$= P$

then the demand charge of a customer becomes

$$\frac{X}{M} \times (O + I + D + P)$$

and the whole charge to the customer =

$$\frac{X}{M} \times (O + I + D + P) + E$$

where E is the energy charge, that is, = rate × kw-hr. sold. This statement for the whole charge to the customer becomes

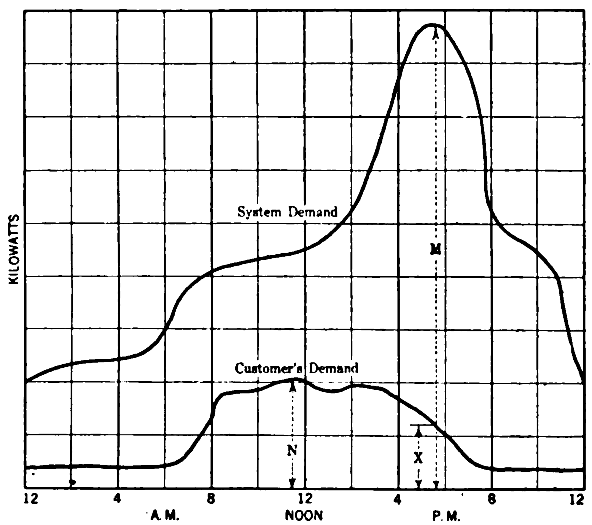


FIG. 3

unsatisfactory when X = zero, as, for instance, when applied to a customer using no current during the hours of the system's maximum demand. Hence, there must be a rearrangement of the equation, such that a term containing the profit and that proportion of depreciation due to operating the system, shall be independent of X.

Thus, if we designate the two portions of depreciation as D_0, depreciation due to operation, and D_f, the depreciation due to life, we can express the customer's charge as follows:

$$\frac{X}{M} \times (O + I + D_0) + (Df + P + E)$$

this of course, becomes

$$\frac{X}{M}(O + I + D.) + (R + \text{kw-hr. sold}),$$

the rate here being sufficient to provide the necessary profit on the investment. Let us express this as

Total charge to customer = $(K \times K) + (\text{output} \times R)$.

R is of course, measured in the regular way, with a watthour meter. *X* must be determined by observation or automatic recording of the customers demand during the period of maximum system demand. The exact time location of the value *X* is of the utmost importance when the customers demand is changing rapidly, as is often the case during the hours of maximum demand on most systems. I have found that a time interval of fifteen minutes in the selection of *X*, would effect the rate by an amount which would result in failure to obtain a large customers business.

It is just here that Mr. Lincoln's thermo logarithmic average meter will prove its value. The great majority of customers taking service from a central station will take their maximum demand during the same period daily that the maximum demand occurs on the system. In this case *X* and *N* for such a customer coincide, and the maximum demand as determined by the thermometer will express exactly the quantity desired. This fact emphasizes the importance of determining the logarithmic in preference to the integrated average, since the determination of plant capacity required to carry the *X* demand of the customer will be subject to the same logarithmic average. Thus, it would appear that Mr. Lincoln has supplied a valuable addition to the rate problem.

The majority of those cases where *N* and *X* do not coincide, are large users of energy and will consequently justify the installation of a graphic meter of the present design, or better, a graphic attachment to the thermometer, or perhaps the use of the printometer.

F. A. Sager (by letter): The simplicity of the device described in Mr. Lincoln's paper is self-evident, and the appropriateness lies in the fact that the same characteristic is used in actuating the device, as imposes the capacity limitation in the power company's system, namely, heating. The overload capacity of the generating equipment will usually impose the limiting condition, although the transforming and transmitting system could be considered if necessary. The fact that generating equipment usually has specified over load capacities for two hour periods would indicate that two hours might be adopted as the time of response for the proposed meters. While this is longer than usually proposed in contracts for electrical energy, in which maximum demand is considered, the adoption of such longer

duration of peak load might work out to the advantage of both power company and consumer.

Under such a plan the portions of rates representing primary charge and kw-hr. charge would have to be properly determined, for the longer time of response, but with this done the interests of the company could be fully protected, and a possible lower rate to customers, to whose load characteristics such lower rate applied, might lead to a far more general use of the many heating and mechanical devices that are now available for use in homes. This presumes that the device can be furnished at a cost small enough to permit of its general use on residence systems. There would seem to be no question about its availability for larger power consumers.

E. P. Roberts (by letter): It seems to me that the analogy to rental of a house or office is not well chosen. Whether or not a house or office is used does not affect cost to the landlord, unless heat and light are included. In fact, the depreciation on a house may be greater when a house is unoccupied than when used.

The fact that the number of maximum demand indicators is only a small per cent of the number of watt-hour meters sold, does not quite justify the statement, " therefore in only this small fraction of the customers for electric energy is any direct attempt made to apply the Hopkinson method of charge;" because, first, a maximum demand indicator is usually used for a number of customers and not permanently installed for only one, and secondly, for many classes of customers the necessity for or advisability of a demand meter is comparatively slight, as the characteristics of use have been ascertained with a sufficient degree of accuracy. Mr. Lincoln refers to changes in characteristics in house service due to use of irons, etc., and the point is well taken, nevertheless the advisability of permanently installing an additional meter in small installations is questionable. It seems to me to have some resemblance to using eight-place logarithms on four- or three-place data.

It might also be noted, that it is the great number of small meters sold that materially affects the ratio of sales of maximum demand to watt-hour meters, whereas the per cent of energy sold based on rates giving consideration to maximum demand is much greater, even though much less than it should be or would be if a satisfactory demand meter were available.

R. A. Philip (by letter): We may concede Mr. Lincoln's premises that a just and logical rate must take load factor into account and that a cheap and accurate method of measuring demand is urgently needed. It should be understood, however, that these premises may not be extended to mean that a rate is not just, equitable or scientifically formed, merely because there is no specific charge based on the consumer's demand, as in the Hopkinson form rate; or no specific differential in the charge for energy, based on the consumers' load factor, as in the Wright demand form of rate; or other explicit recognition of demand or load factor.

Load factor and demand may have been properly taken into account in making a rate, even though the form of the rate shows no evidence of it. Mr. Lincoln brings this point out when he says that a company is justified in establishing a rate based upon a reasonably accurate knowledge of average load factor. That is, a form of rate in which the charge is apparently determined only by the quantity of energy consumed is not unscientific nor is a rate containing a demand element more scientific than one not containing such an element.

A better idea of the position of demand in scientific rate making can be obtained by considering its relation to other important factors.

A scientific or logical rate is one in which every factor involved in determining a proper rate is taken into account in proportion to its importance. A vast number of factors are involved. To fix ideas we may list a few without regard to order of importance: consumption, demand, diversity factor, power factor, voltage, phase, distance from point of production, cost of fuel, rate of interest on money. A rate which explicitly made a proper charge for each and every factor would apparently be a universal rate. An attempt to construct such a rate shows that it is impossible; the number of factors now known is so great that a rate which included all would be so complex as to be incomprehensible. Some important factors are still so vague that their definite determination for a basis of specific charge is impossible. While a specific charge cannot be made to cover each factor the rate will still be logical if each factor is considered and properly weighed in those charges which are made.

As the number of charges must be less than the number of factors, at least one of the charges (and usually each of the charges) must contain many factors besides the leading one which may give it its name. Thus a charge for distance from point of production may be merged in an energy charge, as when a water power company establishes a 12-cent rate for current distributed directly from the power house and a 15-cent rate for current transmitted to distant cities. Diversity factor is commonly amalgamated with demand, etc.

Since the number of charges must be less than the number of factors entering rate making problems, and as each charge even if scientifically determined, is a composite of several factors, a scientific basis is desirable for determining the number of charges.

Some have advocated two charges, consumption and demand, as necessary and sufficient for the universal rate, others have claimed that a third charge, a customer charge, could not be omitted without making the rate unscientific, and that if such a third charge were included the form of rate was ideal.

To determine the number of charges which should be made in a scientifically formed rate, a survey of the past and present rate situation would seem to yield the following conclusions: A rate

which contemplates building up the bills of very small consumers out of numerous separate charges is absurd and therefore unscientific, for science is but a systematic application of common sense. On the other hand, experience has shown that a rate which consolidates all of the factors entering into the bills of very large consumers into a single charge is so inflexible that some of the largest and most desirable customers cannot be secured.

The inference is that a scientific system of rates will start from a single charge for very small consumers and that the number of charges will progressively increase two, three and more as the customers grow larger. Thus the same schedule may at the lower end of the scale, provide a rate depending on one element only, the energy consumed, for the customer who pays a dollar a month, while at the upper end the customer paying thousands of dollars a month may have five, six or more separate charges covering consumption, demand, diversity factor, power factor, price of fuel and other elements.

As the number of charges must be less than he number of factors to be considered, it is important to choose the best factors for erection into a basis of charge and to take them in the best order.

On this point experience seems to have demonstrated beyond the need of further discussion that the first factor to be chosen as a basis for rate making is the consumption. Consequently consumption is the basis of most of the one-charge rates and the principal element in most multiple charge rates. Suitable meters are available for measuring consumption and the availability of such meters is doubtless one of the important reasons why this factor takes precedence over all others as a basis for charging.

The factor which experience seems to point to as a basis for the second charge is demand. The inaccuracy of most cheap methods of determining demand and the great expense of accurate methods has undoubtedly interfered with the use of rates involving a demand charge.

The present paper indicates that a new meter will soon be commercially available for measuring the second fundamental factor of multiple charge rates. The rate situation should be improved in two ways by the introduction of a reliable and inexpensive demand meter. First, disputes and discrimination due to present inaccurate methods of determining demand would be eliminated and second, the dividing line between the one charge and two charge customers may be lowered to advantage as there are many comparatively large customers who cannot be advantageously put on a two-charge rate merely because of a lack of a suitable meter for determining demand.

No improvement in demand meters can, however, be expected to overcome the extra expense and other disadvantages of a multiple charge rate to such an extent that there will not

always remain many customers who may logically be supplied to better advantage on a single charge rate.

An indicating demand meter such as proposed should only be used where the demand charge constitutes a minor part of the bill. The reading of the demand on an indicating scale is a much rougher and more inaccurate process than the reading of the consumption on a watt-hour meter dial; consequently, if energy and demand are the only elements of the rate, it is desirable in order to minimize errors of metering to have the bill depend as much as possible on the energy charge and as little as possible on the demand charge. As energy and demand are but two of the many elements to be considered, the rate maker has considerable latitude in distributing items which are functions of neither consumption nor demand into these two charges and where other considerations do not govern, he should avoid building up those charges which can be measured with least accuracy.

The possibility of measuring kilovolt-amperes as well as kilowatt demand which this meter presents, opens new possibilities of increasing the number of charges in the rates of very large customers. While certain rates now in use recognize power factor as an element, experience has not progressed far enough to indicate clearly what the third factor should be in multiple charge rates. Among the competitors for third place are the customer charge, power factor charge, cost of fuel differential and others. Without deciding in advance that power factor should be the basis of the third fundamental charge it is safe to assume that some form of power factor charge will become a fixed feature of the more complicated multiple charge rates as soon as a suitable meter has been proved available.

Aside from its application to rate making, Mr. Lincoln's demand meter suggests some useful applications. If the meter can be calibrated to indicate in a reliable manner the law of heating of generators, cables, etc., then such meters would become valuable switchboard indicators supplementing or superseding ordinary indicating meters or thermometers as a basis for getting the maximum output from electrical apparatus while simultaneously reducing to a minimum the risk of overloading.

The meter shown in Fig. 10 of the paper should be of great value at the junction point of two power systems, showing at a glance on a single dial the relation between the several elements of the power supplied and taken. In fact, in such a location, where a complicated contract involving numerous separate charges is frequently necessary, the power factor feature would make the meter especially useful in determining charges. For this purpose a permanent graphic record would be desirable and apparently easily obtainable, although if the meter had a large time element, readings of a non-graphic meter marked by hand on a duplicate chart would be almost as good and might even be better if the time of each reading was noted.

H. L. Wallau (by letter): One can readily conceive how easily the instrument described may be arranged for use with both current and potential transformers, thus making it relatively simple to design it for any desired capacity.

It may also be seen that it most probably can be used on direct-current circuits. If in Fig. 2 of the paper we conceive that the resistances *a* and *b* are connected in series and their free ends to the terminals of a shunt, a current will circulate through them proportional to the line current, and in the direction of the arrows marked *E* in that diagram. A connection made from the opposite side of the circuit (from that in which the shunt is inserted) to the wire connecting resistances *a* and *b* in series (top of diagram) would circulate a current proportional to the voltage of the circuit in the direction of the arrows marked *I*. Of course, a limiting resistance would have to be installed in any such connection to prevent a short circuit. The drop across the shunt being very small compared with the circuit voltage, the slight difference in the values of the potential currents flowing in the two resistances would probably not introduce errors of a magnitude sufficient to affect commercial results.

This meter being of a continuous integrating type, as against the present instruments which are, generally speaking, of the periodic integrating type, has decided advantages.

The logarithmic average yielded by it should be welcomed rather than condemned by engineers. All will agree, I believe, that the indicator registering 90 per cent of the demand in a given period of time is preferable to that registering only 63 per cent of it in the same time. A compromise in design is, of course, possible.

The practise of the company with which I am associated is to use a one-hour demand. The 90 per cent meter designed for a thirty-minute period would register 99 per cent of true demand in one hour, and would, therefore, meet its needs. I believe that if this meter were standardized it should be rated as a meter which would register 99 per cent of the integrated demand in a period of time double that required for the 90 per cent. Commercially, this would be preferable, since in most contracts the time interval of the demand is specified, and a thermal meter rated at a period whose duration is one-half that specified in the contract would probably result in heated arguments between company and consumer.

There are, however, some details which may be troublesome. Let us consider such a meter with a loose pointer to indicate the maximum travel of the pointer actuated by the meter mechanism. Let us suppose we have what has been referred to as a 90 per cent meter with a thirty-minute period. Suppose the loose pointer registers 120 kw. while the actuating pointer registers 100 kw., and it is desired to reset the meter to zero. To do this, one of the circuits, preferably the potential through

the indicator, must first be interrupted, thus rendering inoperative the differential heating feature and allowing the actuating pointer to fall back toward zero. Since the cooling and heating of the meter follow the same law, during the first thirty-minute period the actuating pointer will drop from 100 to 10 kw., and in another like period from 10 kw. to 1 kw., which we may assume is sufficiently close to zero for a load of this magnitude. The loose pointer can then be brought back to coincide with the actuating pointer. However, a meter which takes one hour to reset would, generally speaking, be commercially impractical. Mr. Lincoln may have some means to hasten the resetting action, but if so, he has not outlined them.

A combination demand meter, which will register both kilowatts and kilovolt-amperes, if made to operate accurately, should prove of value.

However, let us suppose such a meter is set up on a customer's premises, and that he makes a demand upon the line of 200 kv-a. at 60 per cent power factor. The meter will register 120 kw. of demand with one pointer and 200 kv-a. of demand with the other. If now the consumer adds 40 kw. of incandescent lighting load, increasing his demand to 160 kw. and bringing his power factor up to 71 per cent, the watt pointer will register 160 kw. and the volt-ampere pointer will move up to 226 kv-a. In both of the above instances, the indications of the two loose pointers would correctly show the relation between maximum kilowatts and maximum kilovolt-amperes. But if, instead of adding unity power factor load, the consumer starts up a synchronous motor-generator set, making an additional demand of 40 kw. at 60 per cent power factor leading, his true demand will increase to 160 kw. as before, but his apparent demand will fall to 192 kv-a. If I correctly interpret the results from the description the loose pointers in the second case would register a d mand of 160 kw. and the original maximum kv-a. demand of 200. These latter indications bear no true relation one to another. It would seem, therefore, that with such an instrument a load factor schedule with fixed charges exclusively based on the use of the kv-a. demand would be required, energy charges, of course, being made on a kw-hr. basis. With such a schedule the wattmetei pointer might be omitted, leaving only its mechanism, which is necessary to allow the volt-ampere pointer to indicate apparent energy instead of reactive component. However, the combination of the two indications might more readily influence the consumer to modify his installation so as to operate at the highest power factor obtainable, as it would graphically point to a method of reducing his bills.

As previously stated, a demand meter of low cost is very desirable. It does not follow, however, that a load factor schedule based on the individual consumer's demand for residence business would be at all satisfactory to the majority of residential consumers. The load factor of the average individual residence

is very poor; that of the whole community quite fair. The only devices which to date have made for an appreciable increase in load factor have been the flat iron and the private garage charging set. Perhaps 5 to 75 per cent of the residences have the former, less than 5 per cent the latter. Refrigeration and cooking will have their influences, but while the individual load factor of the former may be from 50 per cent to 80 per cent, that of the latter, with the types of ranges now in general use, is more likely to be from 4 per cent to 10 per cent. Given a large number of such installations, the class load factor will materially improve, due to the large diversity, and warrant a lower class rate, rather than a load factor schedule for the individual. As has been referred to by the author, there are three elements of cost in rendering any service: customer cost, demand cost, energy cost. The order given is the true order of their magnitude with reference to the residence consumer. Practical considerations make it imperative to distribute the bulk of these costs over the kw-hr. consumption.

I believe, therefore, that the forms of residence rates now in general use are preferable to a load factor schedule based on individual consumer's demands. Too great a refinement is to me both unnecessary and inexpedient.

There is, however, a wide field for the application of an inexpensive demand meter to commercial installations. While figures may vary in different localities, a well-developed central station will have 10 per cent to 15 per cent of its total customers on its commercial circuits. With these customers supply companies would gladly install demand indicators, but for the fact that cost considerations make it impracticable to install the available types on more than about 10 per cent of their number.

R. A. Lundquist (by letter): Engineers and operators of electric utilities will generally concur with Mr. Lincoln in his summing up of the essential factors that go to make up the ideal rate.

For the every-day commercial measurement of maximum demand the meter described by Mr. Lincoln appears to approach the solution of the problem.

The theory of his meter seems sound, and to be based upon recognized fundamentals. It is likely also that it can be marketed at a price that will allow its wide use.

In its operation, however, there may be room for question as to its general accuracy. It is assumed that the rating of the resistances will be such that they will not be operated at a very high temperature, and that they will not consume much energy. On this hypothesis, then, will the liquids in each cylinder attain uniform temperatures in the same period of time, regardless of the room temperature? In other words, will the meter indications be accurate over a fair range of outside temperature?

J. D. Mortimer (by letter): The desirability of selling power in large blocks under a rate that recognizes the **investment**

charges upon the generating, transmission and distributing plant, seems to be generally recognized but is not universally applied. Some central station operators have preferred increment energy rates on account of their assumed greater simplicity. The sale of electric power under demand or load factor rates does not seem to have been generally avoided because there was not available a cheap reliable demand meter. Even with a relatively cheap demand meter available, it does not seem at all likely that such meters would be used for measuring the demand of residence electric service because the returns from such service are so low, except where the density of business is very high, as to make necessary the saving of all possible investment in metering devices, and operating expenses in connection therewith. Rates for residence service which do not require the use of a demand meter have been developed, which work substantial justice between different customers of this class.

This is also true of small commercial customers having a connected load of 2 kw. and less. For commercial lighting customers and power customers outside of this range there is an excellent field for the application of a reliable demand wattmeter. Such a device will prove superior in general practise to a demand ampere meter because it will eliminate the error arising from the assumption of a standard voltage and one instrument may be used on three-wire or polyphase service. For the larger power users various types of recording demand meters are now in use and are giving a fair degree of satisfaction. They all call for considerable attention and cost a good deal of money to install.

The device described by Mr. Lincoln appears ingenious and the explanation of its operation seems complete. Whether it will be generally applied depends upon the characteristics it develops in practical operation, the price at which it is sold and the expense of maintaining it in accurate condition. The future utility of the instrument will accordingly be determined from experience.

Central station operators have hoped that the meter manufacturers would develop a combined demand and integrating wattmeter for application to the loads of moderate-sized commercial lighting and power customers. Mr. Lincoln's device is subject to the general objection accompanying all separate demand instruments, namely, that it involves investment in a separate device and calls for the expense of maintaining and operating it. For certain uses it would seem to be superior to any commercial device on the market, and it is hoped that it will be made available for the use of central stations at a not far distant date.

Louis R. Lee (by letter): Where a new rate is being made, it could be based upon this meter to a very good advantage, but inasmuch as present rates are more or less established we are forced to consider the meter with reference to its applica-

tion to them. As stated in Mr. Lincoln's article, the average load factor for residence lighting is pretty well known, so that in this discussion the application of a heat-storage meter for residence application has not been considered, as it is not believed that the additional information which will be obtained, would compensate for the increased cost.

The power contracts of the Tennessee Power Company and allied companies, involve a graduated consumption charge and also a demand charge based upon the average maximum 5-minute demand. This demand is obtained by the use of graphic wattmeters and is arrived at by averaging the highest 5-minute demand for each day. It may seem that a great deal of unnecessary trouble is involved in obtaining this demand but from the following considerations, it seems to be the most equitable value that could be used.

In the first place, the idea of the demand charge is to cover fixed charges necessary to handle the demand both at power station, in the distributing system and in service transformers. In the power station the portion of the total fixed cost which any individual customer should be charged with, would be based upon his average demand during the peak load on the power plant. For the distributing system and service transformers, however, the amount which would be chargeable to the individual customer would depend upon his maximum demand regardless of the time of its occurence. It is evident that the average customer's share of the station peak load would be less than this last figure. It is also evident that the maximum demand, on which the latter portion of this charge is to be based, is higher than the customer's average maximum demand. Therefore, by taking a demand such as we have mentioned above, a figure is arrived at which is higher than the demand upon which the central station portion of the demand charge is to be based, and at the same time, is lower than the demand on which the distributing system and transformer portion of the demand charge is to be based. In other words, it falls somewhere between these two values and, on the whole, comes nearer to taking into account both these factors than any other figure for the maximum demand which could be used.

For this reason, therefore, the heat-storage meter is considered with reference to its application to this condition as it does not seem desirable to modify the rate to conform to the characteristics of the meter. As stated above, curve-drawing watt-hour meters are used at present, the curve sheets being removed about every three days and very satisfactory results are obtained, except, that the cost of such meters is rather high and considerable attention is required to keep them in adjustment. Of the heat-storage meters a 10-minute 90 per cent meter would seem to be best adapted for this rate, consequently, it has been considered in the following discussion of its adaptability.

In arriving at the following values for the heat-storage meter readings, a logarithmic curve plotted between time as abscissas and per cent as ordinates was used. For the 10-minute interval, the values of this curve range from 10 per cent to 100 per cent. In arriving at the reading of the meter for any 10-minute load, the average value of the load, for each minute, was multiplied by the corresponding ordinate of the above curve and the sum of these products was then divided by the sum of all of the ordinates of the curve. In figuring on the 90 per cent meter rather than the 63 per cent meter mentioned in Mr. Lincoln's article, it was considered that for the short demand period, the indications of the 90 per cent meter would be more nearly correct on the whole than those of the 63 per cent meter,

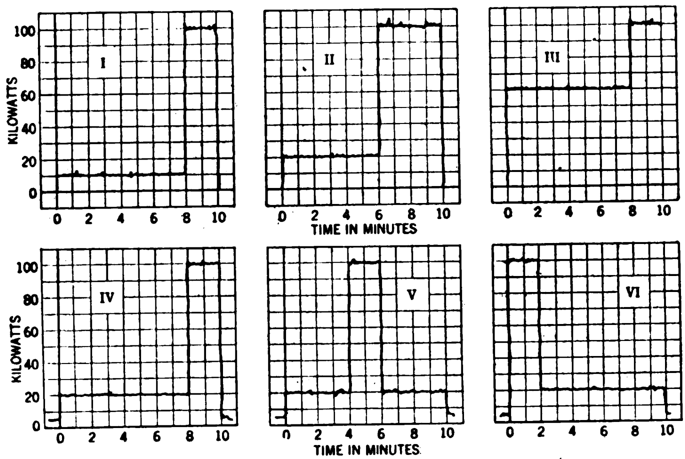


FIG. 4

even though with very short duration maximum demands, the results obtained would be very much higher than the average value of the load during this time.

The comparison of the heat-storage meter with the curve-drawing meter for our rates will depend upon the following points:

Accuracy. Sketches I, II and III of Fig. 4 show a series of 10-minute loads for which the readings of the heat-storage meter have been computed A comparison of the readings of two types of meters for these three 10-minute loads is given in the following table:

Sketch	Heat-Storage Meter Reading	Graphic Meter Reading
I	42 kw.	28 kw.
II	66	52
III	69	68

For these 10-minute loads, it will be noticed that in each case the reading of the heat-storage meter is higher than the average load, the amount of difference depending roughly upon the relation of the maximum to the average values of the load and upon the time of occurrence and duration of the maximum value. With a rate of the nature mentioned above, the heat-storage meter would work out to the advantage of the central station, probably too much so. Sketches IV, V and VI show 10-minute peaks which have the same average values and the same general characteristics, except, that the location of the maximum value varies in the three cases. For these cases the comparison of the two meters is as follows:

Sketch	Heat-Storage Meter Reading	Graphic Meter Reading
IV	47.6 kw.	36 kw.
V	29.8 „	36
VI	22.2	36

It will be noted that the value of the heat-storage meter reading in each case is computed with the 10-minute interval ending at 10 as shown on the curve. It is of interest to note that in V, if we consider the 10-minute as ending at (*a*), the reading of the heat-storage meter would be 44.6 kw. In VI, if the period ends at (b), it will be 28.6 kw., or if it ends at 6 it will be 37 kw. The maximum values which would be obtained, therefore, for the three cases would be 47.6, 44.6 and 37 kw. In these three cases we have demands that are practically indentical and would cause the same disturbance on the system of the central station. Yet with the heat-storage meter, it would be not possible to obtain the same values for the maximum demand. In this connection, it might also be mentioned that for two individual peaks preceded by different average loads, the indications of the heat-storage meter would also be somewhat different. Another point of interest in this regard is, that the heat-storage meter would penalize comparatively high short peaks, while in cases where the peaks were a little above the average load and of comparatively long duration, the heat-storage meter would give about the same results as the graphic meter. It would seem therefore, that for a 10-minute maximum demand meter, the heat-storage meter would leave much to be desired.

Reliability. While there are no actual experience data available as to the comparative reliability of the two types of instruments, the heat-storage meter would probably be the more reliable and free from changes in adjustment. After it was once installed, however, it would not be as easy to secure a rough check on it from the accompanying integrating meter, as it would be with the graphic meter now in use.

Cost. Under this heading both the initial cost of the two meters and also the operating cost must be considered. With

the type of heat-storage meter in which the reading is given by pointer, which is moved up to the maximum position, and is left there to be reset, there is no permanent record of the demand which can be produced in case any arguments arise as to the bill, so to put it on the same basis as the graphic meter in this respect, it would be necessary to have a curve drawing heat-storage meter. This additional feature could easily be worked out but it is doubtful whether there would be any great differences between the cost of an ordinary graphic meter and a graphic heat-storage meter. Without this feature, however, the heat-storage meter would not be comparable with the graphic wattmeter, as it is found in practise that the permanent records of the latter are of great value where these disagreements arise as to the application of the rate. Unless a graphic form of heat-storage meter were used a greater amount of attendance would be required in order to obtain the readings than is required by our present rate. With the graphic wattmeter, the curve runs along for about three days before it is taken off, while with the heat-storage meter, the readings would have to be taken every day, and the pointer reset, unless a graphic form were used, in which case, there would be very little difference in the initial and operating costs. Therefore, putting the watt meters on the same basis, the heat-storage meter would have little advantage in cost.

Heat-Storage Meter Contract. As to the suggestion that present contracts might be altered to permit the use of the heat-storage meter, it would be of interest to know just how the indications of this meter would be specified in the contract. We have found, from experience, that the average customer would not consent to a contract merely stating that the maximum demand was to be taken as the indications of the heat-storage meter without further explanation. Obviously, the use of this meter would not be permitted by a provision saying that the maximum load over a certain interval would be considered, nor that the average load over a certain interval would be taken, as the heat-storage meter, strictly speaking, would not give readings which would come under either of the provisions, except in certain special cases. It would, therefore, be of interest to hear suggestions as to just how the use of the meter would be specified in a power contract.

Paul M. Lincoln: Mr. McClellan said that he thought the necessity of measuring maximum demand had been considerably exaggerated. I do not agree with that. I think that the measurement of maximum demand is absolutely essential, if we would have a logical method of applying rates for electric service.

Mr. Lieb also made the same point, and as I understood him, said that it was not necessary to discriminate between customers of a given class on account of their load factor. I do not agree with that, and I believe, on analysis, that that position cannot be sustained.

John Hopkinson was the first to point out, many years ago, that the cost of electric service was dependent on the two factors, maximum demand, and the energy used; and his analysis also shows that even a larger part of the cost depends upon the maximum demand than upon the kw-hr. of consumption. Therefore, if you are going to render a logical bill depending upon the cost, the greater part of the bill will depend upon the maximum demand.

My friends will probably counter by saying that the proper charge for electric service should not be a function of the cost of power, so much as of the value of the service rendered. I am not going to discuss the question of the "cost of service" versus the "value of service" theory; it is not necessary, because the value of service must be always measured in exactly the same terms as the cost of service. That comes from the consideration that the value of service can never be greater than the cost to the customer of supplying his own service, and the cost to the customer supplying his own service must always be measured in the same terms as the cost of supplying that same service from a central station; therefore, when we have so analyzed as to get a rate which is properly dependent upon cost of service, we will also have one which is in exactly the same terms as the rate which depends upon the value of service. We come down to exactly the same thing, whether we use cost of service or value of service.

By the way, Mr. Lieb and Mr. McClellan and these other gentlemen who criticised me upon that point, all of them admit by their practise that it is perfectly proper and logical to use kw-hr. in discriminating between the various customers, of the same class. If they admit that, they must also admit that it is proper and logical to use a maximum demand meter to discriminate between customers, because as Hopkinson pointed out twenty-three years ago—and every other analysis of power costs has pointed out since—a customer's bill should be dependent even more upon maximum demand than it is upon the kw-hr. used; so that if these gentlemen use and admit that the use of kw-hr. meters for discrimination between customers is logical and correct, I do not see how they can escape the conclusion that the maximum demand meter is necessary also.

Mr. Cheney spoke of the undesirability of using maximum demand in connection with residences where the maximum demand for the month may be set by the one entertainment that the owner of the residence gives during the month. That point is well taken, and for that reason I am of the opinion that the maximum demand meter as applied to residence service cannot successfully work out. There are other modifications of a maximum demand rate which I think will apply, and which will be further treated in a future paper.

Simplification of rates has been urged, and I agree entirely

that simplification is a highly desirable thing to have. However, I do not believe that it is desirable or logical to obtain simplification in rates at the expense of justness and fairness, and if one of those elements must be sacrificed, I think the simplification will have to go.

Mr. Lieb also mentioned the point that it was not necessary to discriminate between customers on the basis of load factor, but I have already answered that point; I maintain that if Mr. Lieb uses kw-hr. meters to discriminate between customers, it is also logical for him to use maximum demand as well: I simply reiterate that point.

Mr. Hall gave us a very interesting discussion of the Type H meter, and seems to indicate that in designing that meter they have been after a straight-line function between time and load. I do not believe that the straight-line function is the one to go after, as I indicated in my paper. The proper function is the natural logarithmic function, since that is the function that the apparatus will follow in its own heating, and it is that same kind of function which should fix the bill. I believe that what in my paper I call the "logarithmic average" is a more just basis for fixing rates than is an average of the usually accepted type; that is, where each instant over which the average is taken has an equal weight.

Mr. Hall also gave us some information concerning the characteristics of the Type H meter, and stated that it made no difference whether a quarter-inch lead was used, or some small wire. I would like to ask, and suggest that there would be a very decided difference between those two conditions if the outside temperature of those leads differs from air temperature. Also, a marked difference between lead temperature and air temperature cannot be avoided if the lead runs out of doors into a colder atmosphere, or a hotter atmosphere. The size of those leads under these conditions will make a very great difference in the indication.

Mr. Hall also asked concerning the ascending and descending curves of the meters I have described. Those two conditions have exactly the same characteristics, and the characteristics depend solely upon the fact that a hot body will lose heat in proportion to its elevation above the surrounding air. That is perfectly true so long as convection only dictates the rate of the loss of heat, this in turn is true only when the temperatures are kept below about forty degrees or thereabouts, and the surfaces are polished. So long as that is the case, radiation hardly enters at all into the escape of heat from the body; it is controlled entirely by convection, and the law of the loss of heat by convection is a straight-line law.

Mr. Taylor criticises me for spoiling a good meter description with a discussion on rates. Now, I maintain that the crux of the rate problem lies in the method of measuring; you cannot separate those two; and I also maintain and will continue to

maintain that there can be no logical or just method of applying a rate for electric service until we have some means of getting information other than the simple kw-hr. of consumption. It is absolutely necessary to recognize load factor if we are to have a just rate. That is the main point I have tried to emphasize in my discussion of the rate problem, per se.

Mr. McClellan, in speaking the second time, emphasized the fact that it was value of service rather than cost of service that should control the rate. As I indicated in my opening, it makes no difference whether you take the value of service theory or the cost of service theory; they must be measured in the same terms; the same quantities must enter into the measurement of either the value or the cost.

Mr. Goodwin has asked how this meter is to be used on direct current. I did not intend to convey the impression that the meter I described was applicable to direct current, but the principle is applicable to direct current. Suppose in Fig. 5 we have a generator *G*, and we bring its current through a shunt,

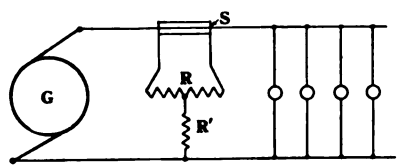


FIG. 5

S; across this shunt we place a resistance *R*. Then, from the opposite polarity of the generator, we take a current through the resistance *R'* into the middle point of resistance *R*. You will find if you analyze the direction of current flow that you have in these two halves of the resistance *R* exactly the same condition which I have described in Fig. 2 of my paper, and that the difference in the rate of heating in the two halves is proportioned to the watts. However, the scheme is not applicable to direct current, because a meter of that kind would take about as much power in the meter shunt *R'* as would be used in the load. The only way to make the scheme generally applicable to direct current is to use something which is equivalent to a d-c. transformer, something which is unfortunately not yet available.

Mr. Burke mentioned the desirability of a rate which is based upon excess above a certain quantity of demand. There is in my opinion a great possibility in that particular method of measurement, and it is one which will be treated in my future paper.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 8, 1916.

THE A. I. E. E. AND THE TECHNICAL COMMITTEES

BY DAVID B. RUSHMORE

ABSTRACT OF PAPER

The rapid growth of the science of electricity and the increase in membership and the activities of the American Institute of Electrical Engineers, have brought about a situation where the present form of organization and method of procedure fails to meet all of the demands of its members for professional activities in this line. The paper points out the difficulties of the situation, makes a tentative suggestion, and brings up a number of points involved, on which discussion is invited in order to assist those who are considering the possibility of somewhat modifying the Institute's organization to meet these new demands.

A STRIKING characteristic of the present time is the extremely rapid rate of increase in knowledge, together with the fact that the mental capacity of man and the time available for his activities remain practically constant. The result is naturally the limitation of an individual's activity to a part of the field which is becoming continually narrower, bringing about an increase in specialization and specialists.

Engineering, which was formerly divided only into military and civil fields, is now much subdivided and not a few of the technical societies have many subdivisions and ramifications of their own.

An enlarged scope of activity and a change in external conditions, whether with an individual or a society, naturally demands a readjustment of organization to bring about proper adaptation. Therefore, the universal law that there can be no life without change or growth, whether of individuals or organizations. The natural tendency of many minds to cling to things as they are is beneficial only in balancing those other minds, usually associated with youth and virility, who are striving for progress and development.

Knowledge must always be incomplete and its interpretation therefore imperfect. So, theologies, creeds, laws and constitutions must all undergo continual change and revision to

Manuscript of this paper was received January 10, 1916.

adapt themselves to a deeper insight and a broader vision of nature and her manifestations.

Where a science is growing as rapidly as is that of electricity, and where a profession is expanding by such leaps and bounds as is that of electrical engineering, the demands upon such an organization as the Institute increase proportionately, and a serious and important responsibility devolves upon its membership of meeting this situation with the proper development and modification in the organization of the society.

The object of a technical society such as the Institute is to supply a natural demand for certain necessary activities required or desired by the individual who is practising the profession of electrical engineering, and where these have not been supplied, either with sufficient promptness or in sufficient quantity, by the Institute itself, as well as for other reasons, the result has been the formation of a large number of independent societies which are carrying on lines of activity over-lapping to a greater or less extent those of the Institute.

Naturally, the functions of any technical society must grow to include many things which its founders could not have foreseen. For many years the Institute had no technical committees. The growth of these has been gradual, one or more usually being added every year. The possible number of these technical committees, if the work of Electrical Engineering in all of its ramifications is to be taken care of in this way, will be very considerable, and it would appear more than the present method of procedure in the Institute can well take care of. At present, the Institute has the following technical committees:

Power Stations Committee.
Transmission Committee.
Railway Committee.
Protective Apparatus Committee.
Electric Lighting Committee.
Telegraphy and Telephony Committee.
Committee on Use of Electricity in Marine Work.
Electrochemical Committee.
Electrophysics Committee.
Industrial Power Committee.
Committee on Records and Appraisals of Properties.
Educational Committee.
Committee on Use of Electricity in Mines.
Iron and Steel Industry Committee.

These are the result of a historical growth and not of any general plan. Apparently a very much better and more logical

subdivision of the field of electrical engineering is that used in connection with the plans for the International Electrical Congress, which is as follows:

1. Generation, Transmission and Distribution.
   Central station and substation design, control and operation.
   Long-distance transmission of electric power.
2. Apparatus Design.
   Generators, motors and transformers. The rating of machinery.
3. Electric Traction and Transportation.
   City, surface and rapid-transit railways; interurban and trunk lines; electric vehicles; ship propulsion, mining railways, elevators and hoists.
4. Electric Power for Industrial and Domestic Use.
   Factories, mills, refrigeration, heating devices, etc.
5. Lighting and Illumination.
   Arc and incandescent lighting; the science and art of illumination.
6. Protective Devices: Transients.
   Switches, circuit breakers; condensers; electrostatics; disruptive phenomena; high-frequency phenomena.
7. Electrochemistry and electrometallurgy.
   Electrolytic and metallurgical apparatus and processes.
8. Telegraphy and Telephony.
   (a) All communication of intelligence by wires.
   (b) Electromagnetic waves and radio-telegraphy and telephony.
9. Electrical Instruments and Electrical Measurements.
   Switchboard, portable, standard and absolute instruments.
   Testing and standardization methods; absolute measurements.
10. Central Station Economics.
    Load factors, power factors, measurements of maximum demand and all problems affecting the economy of central stations; also rates, their regulation and legislation.
11. Electrophysics.
    Radioactivity; Röntgen rays; gas and vapor conduction; electron theory; constitution of matter, etc.
12. Miscellaneous.
    Such as history and literature of electrical engineering; symbols and nomenclature; engineering education and ethics.

These general divisions are naturally subject to a very considerable number of subdivisions, as for instance in the field of industrial power, which, divided into Industries and Classes of Service, includes, amongst other things, the following:

Industries:

agriculture
automobile
bakeries
boiler works,
bottling works
box factories
breweries
brick factories
broom factories
building construction
candy factories
carpet and rug factories
cement
clothing
corn mills
cotton mills
cotton oil seed mills
creameries
dairies
dye works
flour mills
foundries
freight handling
glass factories
glove factories
hardware manufacture
harness factories
ice machines
irrigation
knitting factories
laundries
lumber mills
machine shops
mattress and spring factories
meat packing
mining
paint works
paper box factories
paper and pulp mills
piano factories
pipe mills
planing mills
porcelain factories
railways
refrigeration
rubber industry
shoe factories
shoe repairing
soap factories
spice factories
steel mills
stone quarries
stove factories
sugar industry
tanneries
textile mills
tile factories
tobacco factories
trunk factories
wagon factories
wall paper factories
wood-working factories
woolen and worsted mills.

Classes of Service:

air compressors
blowers
coal cutters
concrete mixers
conveyors
cranes
crushers
dental appliances
dredges
elevators
exhausters
fans
hoists
ice cream freezers
lime kilns
locks
pumps
printing presses
rock drills
sewing machines
ship propulsion
towing machinery
turntables
vacuum cleaners
vehicles
washing machines.

We have electrical experts on the iron and steel industry who confine all their attention to these fields. We have other experts on the use of electricity in mines, in cement mills, in machine shops, and these experts are to be found not only in the manufacturing companies but also in the industries themselves.

It is apparent that the Institute in its present form will not long supply the needs of the members for the information which they wish in electrical engineering on their special lines, and that the Institute's organization and activity must undergo modifications, or we must continue to see an increasing number of auxiliary societies formed, each with its special organization, membership, transactions and conventions, with the attendant expense in time, energy and money.

Some of the societies which in whole or in part duplicate work which might have been included in the Institute's activities, are as follows:

American Electric Railway Association.
American Electrochemical Society.
American Institute of Consulting Engineers.
Associated Manufacturers of Electrical Supplies.
Association of Edison Illuminating Companies.
Association of Iron and Steel Electrical Engineers.
Association of Railway Electrical Engineers.
Association of Railway Telegraph Superintendents.
Electrical Contractors' Association.
Electrical Manufacturers' Club.
Electric Salesmen's Association.
Electrical Supply Jobbers' Association.
Electric Power Club.
Electric Vehicle Association of America.
Illuminating Engineering Society.
Independent Telephone Association of America.
Industrial Electric Heating Association.
Institute of Operating Engineers.
Institute of Radio Engineers.
International Association of Municipal Electricians.
International Electrochemical Commission.
National Arm, Pin and Bracket Association.
National Association of Electrical Inspectors.
National Electric Light Association, Technical Section.
National Electrical Contractors' Association.
Railway Signal Association.
Society for Electrical Development, Inc.
Society for the Promotion of Engineering Education.

In this connection it is interesting to view the form of organization developed by a number of other societies, such as the American Association for the Advancement of Science, and in connection with the present and prospective development of the technical committee the work in the local Sections and its relation to such committee work becomes of interest. Of its own initiative, one of the Sections this year appointed a local Committee on Industrial Power, and when this was brought to the attention of other Sections a number of these have taken similar action. Plans are under way to have the main committee cooperate with these local committees and in this way a coordination of effort of those interested in a particular line can easily be brought about. In formulating plans for the Industrial Power Committee at the beginning of the year it was suggested that the committee be composed of a representa-

tive from each Section, which representative might be the chairman of a local Industrial Power Committee, where the field existed for the usefulness of such. This step, however, appeared rather radical to some and was therefore postponed.

The present expense in connection with the publication of the PROCEEDINGS and TRANSACTIONS is now very large, and it is evident that were these committees all to be of equal activity and to supply through the Institute publications the necessary information desired by specialists in all of the different fields, an impossible situation would result. It is therefore evident that the time is approaching when some new policy concerning the activities of these technical committees should be decided upon. At the present time the matter is simply drifting, some of the technical committees being very active and others apparently do not meet at all during their existence.

While there is no doubt of the ability of the Institute to meet the situation, it would seem that a definite choice must soon be made regarding the policy for the technical committees, and the basis of such a decision must be the point of view which will, in general, be held regarding the proper functions and field of activity of our organization. Essentially, it resolves itself into a decision as to whether the Institute is to remain the common, central organization covering the entire field of electrical engineering, and having for its membership all those who are electrical engineers, or whether it is simply to cover the residue of work not taken up by the present and future special engineering societies and with a future importance which may or may not be what its present membership would desire.

The problem is before us and it must be solved. The future ramifications of electrical engineering will evidently be manifold, and the relation of this profession to the other engineering professions must become more intimate as the uses of electricity in other fields increase.

There is no reason why, with a proper study of conditions and thought, the organization of the Institute cannot be adapted to take care satisfactorily of any size of membership and any multiplicity of fields of interest and activity which it should properly cover. The problem has been solved in many spheres of activity and will assuredly be solved in ours.

Do the members of the American Institute wish to see their society cover simply the residue of work which is not of interest to specialists in the different fields, or do they wish to see the

organization properly modified and expanded so as to cover the entire field of electrical engineering?

Has the time arrived when the work of the technical committees can properly be developed into a more systematic and useful activity for the men interested in different lines, and, if so, how can this best be done?

Would it be desirable for the technical committees to slowly develop engineering handbooks on the particular fields they would cover, and to keep these up to date, these being the authorities for the profession in the various lines?

Should the technical committees—as the Industrial Power Committee has in mind as an experiment this year—prepare annually a report which is made by the committee as a whole and which gives to the membership with its varying interests the published information desired in that field of activity?

Has the time approached, or is it likely to approach, when it will be desirable for the main body of the Institute to consider development along the lines of a holding company, with the various Sections within it crystallized somewhat along the lines of distinct divisions?

Is it desirable for the Institute to attempt to bring back into its fold by offering a proper form of organization and autonomous government, such organizations as cover a purely electrical engineering field and which are now operating as separate societies?

Should there not even now be relations, more than exist at present, between the chairmen of the various technical committees, so as to harmonize their work and to bring about a more uniform activity in their respective fields?

Would it not be desirable for the President to meet monthly with the chairmen of these technical committees and to consult regarding their work, which is such an important part of their work, the same as he does with regard to the more governmental functions with the Board of Directors?

Is the time approaching when it would be desirable to allow the chairmen of the technical committees to be elected by the groups of men who would be especially interested in their fields of endeavor, and to allow these men some voice in the activities in these distinct fields?

What proper relation can the technical committee, or its successor, have with the trade papers in the particular fields, and what is its best line of work in connection with the Mem-

bership Committee, with the Standardization Committee, and with the local Sections?

Should there not be developed more than at present some central, unified organization wherein all the different societies could be brought together and a greater degree of harmony and cooperation of work assured?

What definition of field of activities can be drawn between the work of the American Institute and that of other organizations now partially covering the same fields?

Should we not have some permanently established and efficiently active medium of relationship between the Institute and such more commercial organizations as the National Electric Light Association, Electric Railway Association, and others, to arrange for a better cooperation in fields where such a unity of interest distinctly exists?

Is the present method of conducting the Institute and similar organizations, with the presentation of papers, the methods of discussion, and succeeding publication and distribution, the best that can be evolved or, if not, what improvements can be suggested?

The points brought up here have to do only with such activities as affect, in greater or less degree, the fields covered by the technical committees. The larger subject regarding engineering organizations, their proper and future relationships and cooperation, is worthy of equally careful study.

That the Institute will rise to the present emergency is naturally assured. The object of this paper is to bring out a broad and thorough discussion on the subject, which may be of assistance to those who have under consideration this all-important subject.

These are a few of the questions before the Institute, and on their proper and early solution and determination of a constructive policy depends to not a small degree the future of the organization which has played such an important part in the past and before which lies a future to be determined only by the vision and activity of its members.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 8, 1916.

THE CREST VOLTMETER

BY L. W. CHUBB

ABSTRACT OF PAPER

The demand for testing dielectric media in terms of crest voltage has resulted in several schemes of measuring high voltage. The paper mentions and compares some of the methods of high-voltage measurement and describes in more detail the crest voltmeter which has been found to be more satisfactory in commercial testing than the spark gaps which have been adopted by the Institute in the Standardization Rules. The construction, operation, accuracy and applications of the crest voltmeter are briefly described. The present Standardization Rules for the measurement of high testing voltages recommend spark gap methods which under certain conditions are impractical, inconvenient, and dangerous. The summary states that the spark gaps should be only a calibrating standard and a more practical instrument, such as described, the preferred working standard.

WITHIN the last few years the importance of making careful dielectric tests of insulation has been emphasized and several papers have been presented which deal with meters and apparatus for adjusting and reading the value of the testing voltage in high-voltage testing circuits. It is the purpose of this paper to describe a late modification of such a meter, to compare it with the sphere spark gap adopted as a standard by the Institute, and mention the relative merits of some of the common means of measuring high voltage in practical testing.

At ordinary frequencies, breakdown of dielectric media is dependent more upon the crest or maximum value than the r.m.s. value of the voltage wave, and for commercial testing it is desirable to have quick and accurate means of measuring voltage, which will give an indication proportional to the crest value of the testing wave under testing conditions. A meter for this purpose should preferably derive its voltage from the high-tension winding. It should be convenient, safe, direct reading, independent of atmospheric conditions and cause no oscillatory disturbances which will damage apparatus under test.

The needle and sphere spark gaps are the crest voltmeters which have been adopted by the Institute as a working stand-

Manuscript of this paper was received January 7, 1916.

ard. Careful calibrations of the spark gaps have shown that between certain limits and at commercial frequencies they give accurate indications of crest voltage when the necessary corrections for temperature, barometric pressure and humidity are made.

The possible accuracy of the spark gap, however, is not sufficient justification for its use in commercial testing, for it meets none of the other important requirements.

Other voltage measuring means, corrective schemes and types or modifications of crest voltage indicators have been described[1] from time to time, some of which meet the requirements.

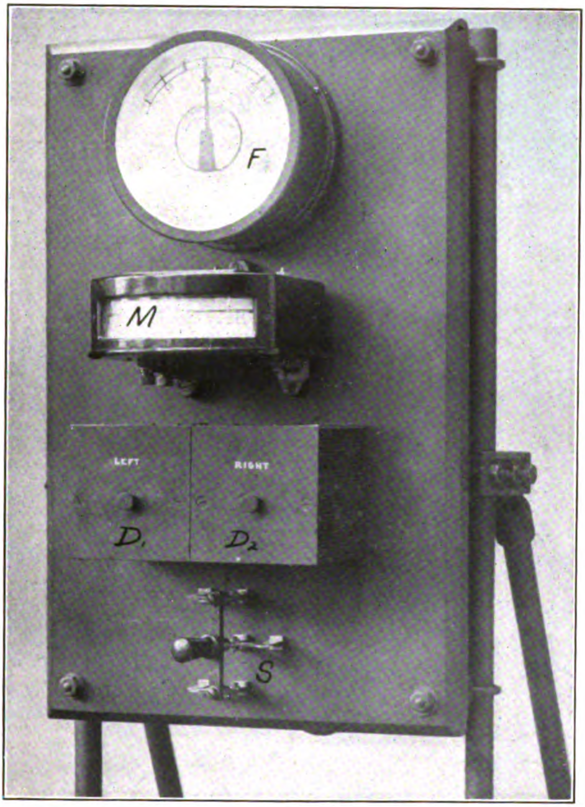
Direct measurement of high-tension voltage with the electrostatic voltmeter and derivation of high-tension voltage from the primary voltage, from auxiliary ratio transformer, from tertiary coil placed in the transformer or from section taps on the secondary winding have been the most common methods used. Generally r.m.s. voltage is read, assuming the voltage wave to be sinusoidal. When testing apparatus of high capacitance and at high voltage, the ratio of transformation is affected and the wave is often so distorted that corrections for ratio and crest factor should be made. With some of these methods, and under certain favorable conditions with all of the methods, corrections can be made, but in the majority of cases such corrections are too laborious or too much in error to be worth while.

In former papers schemes of correction for crest factor have been given. Some of these have since been combined with certain improvements into an instrument especially suited to dielectric testing, equally accurate and very much more practical than the spark gap.

The Crest Voltmeter

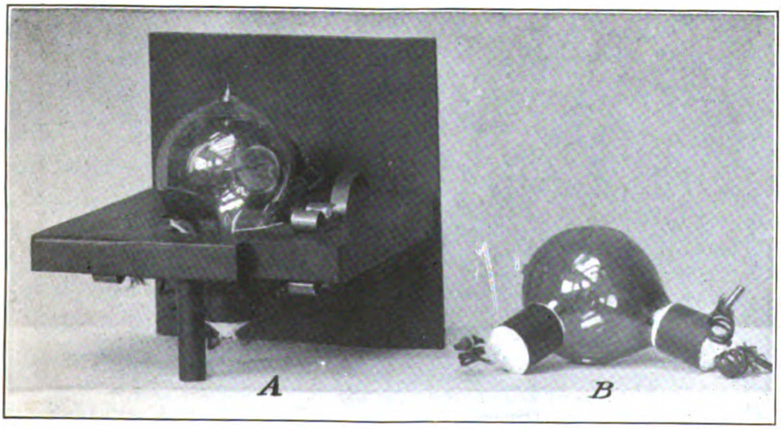
Historical. In a paper[2] on the calibration of the spark gap, an absolute method of measuring the crest of an alternating voltage wave was described. By means of a rotating contactor and d'arsonval galvanometer, or d-c. voltmeter, the charging current to a guarded air condenser was integrated and from it the peak values of a symmetrical voltage calculated. In some

1. Sharp and Farmer, Trans. A. I. E. E., Vol. XXXI, 1912.
   Chubb and Fortescue, Trans. A. I. E. E., Vol. XXXII, 1913.
   Whitehead, Trans. A. I. E. E., Vol. XXXII, 1913.
   Whitehead and Gorton, Trans. A. I. E. E., Vol. XXXIII, 1914.
   Middleton and Dawes, Trans. A. I. E. E., Vol. XXXIII, 1914.
2. Chubb and Fortescue, Trans. A. I. E. E., Vol. XXXII, 1914.



[CHUBB]

FIG. 1—CREST VOLTMETER



[CHUBB]

FIG. 3

A—Hot cathode valve mounted in self-connecting drawer.
B—Hot cathode valve disconnected.

later work, Whitehead and Gorton substituted mercury arc rectifiers for the rotating contactor and the Moscicki type of condenser of measured capacitance for the air condenser of figured capacitance. The change from the mechanical rectifier was made to allow measurement at high frequency and to the glass condensers presumably for convenience. In the latest modification, described in this paper, the hot cathode tube is substituted for the mercury arc rectifier and the whole apparatus arranged in compact form to make a practical measuring instrument for the testing department or laboratory.

Construction. Fig. 1 shows one type of instrument mounted on a small panel to be placed near the control apparatus of the testing transformer. It consists of a permanent magnet instrument (M) sensitive to low currents, two small hot cathode

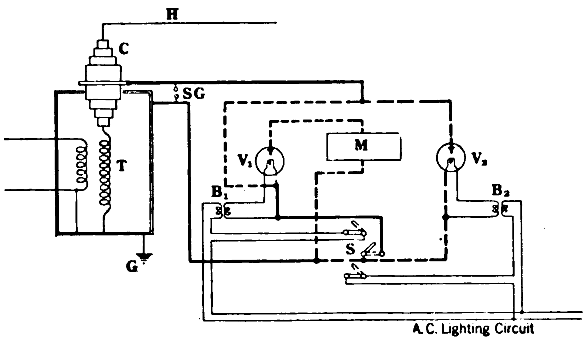


FIG. 2

valves mounted in the drawers (D_1D_2), a frequency meter (F), an exciting switch (S), and on the back the necessary wiring, resistors and two bell-ringing transformers for heating the cathode filaments of the valves.

The high-tension condenser terminal of the transformer or other separately mounted condenser is used in connection with the meter panel. When the transformer terminal is used, it is insulated from ground and the crest voltmeter is connected between ground and the outside flange of the terminal.

Fig. 2 shows the diagram of connections, in which T is the testing transformer diagrammatically shown in a grounded case; C is a condenser terminal used to bring out the high-tension lead (H); V_1 and V_2 are two rectifiers or valves shown in detail in Fig. 3 and having an anode of tungsten or molybdenum and

a cathode of incandescent tungsten working in an atmosphere of mercury vapor, or one of the noble gases at low pressure. The filamentary cathodes are heated by the secondary current from two bell-ringing transformers, B_1 and B_2, the primaries of which are connected to any suitable a-c. lighting circuit; M is a permanent magnet indicating instrument connected in the anode lead to the valve V_1; S is three single-pole switches operated with a single handle and used to close the cathode heating circuits or short-circuit the instrument when not in use; $S.G.$ is a safety gap between the leads to the meter to protect the insulation of the apparatus in case of interruption in the supply to the bell-ringing transformers when the switch is in the working position, or in case of an accidental open circuit in the instrument wiring. The frequency meter shown in Fig. 1 is not an essential part of the measuring apparatus but may be included to make a proportional correction when the frequency varies appreciably from normal.

Operation. The condenser terminal or other condenser connected to the high-tension lead takes a charging current at all times proportional to the differential or rate of change of voltage across its terminals. At both the positive and negative maxima of the voltage waves this current is zero and the time integral or area of the current wave between these zero values is a direct measure of the difference between the maximum and minimum voltages. On account of the asymmetrical conduction of the cathode valves, the arrangement of circuits shown in Fig. 2 is such that the charging current in one direction passes through the instrument M and the valve V_1 as shown by the heavy dotted line. Current in the opposite direction passes through the valve V_2 without passing through the meter, as shown by the heavy broken line. The light lines in the figure represent the primary and secondary exciting circuits for the cathode filaments fed from the lighting circuit. When the meter is not in use the switch is thrown to the right, which short circuits the apparatus and opens the primary circuits of the exciting transformers.

The torque of a permanent magnet meter is proportional to the average value of the current passing through it, and since for waves of constant length the area is proportional to the average height of the current, it is evident that the meter will give an indication proportional to the time integral of the pulsating current through the valve V_1 and this will in turn be proportional to the crest of the voltage wave.

Calibration. The instrument is calibrated in parallel with the standard spark gaps or another standardized crest voltmeter and usually the scale drawn so that it indicates the r.m.s. value of a sine wave having a crest value equal to that of the voltage wave to which it is connected. When thus calibrated it is the equivalent of the needle or sphere gap.

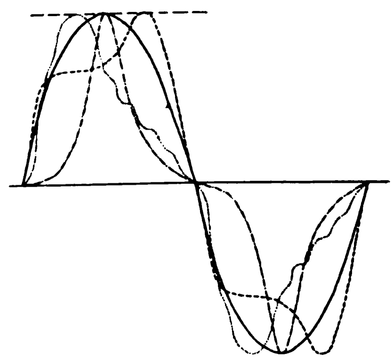


FIG. 4

Accuracy and Corrections. With the rotating contactor commutating at symmetrical zero points in the current wave, the indication of the instrument is theoretically correct with all wave shapes containing only odd harmonic components at the fundamental frequency at which it was calibrated. On unsymmetrical voltage waves containing even

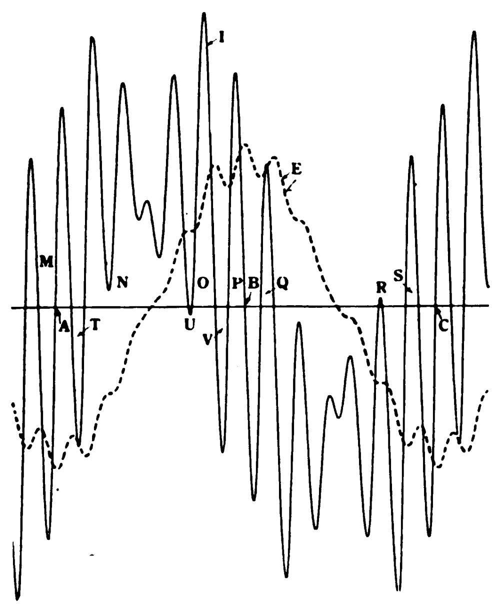


FIG. 5

harmonic components (which seldom, if ever, exist in testing work) the instrument will indicate the mean between the positive and negative crest values.

With the rectifier valves, any of the waves of Fig. 4 will give the same indication and the crest voltmeter will give a theoretically correct reading. With waves having more than one maximum and one minimum per cycle there will be an error depending upon the depth and number of ripples in the wave. Fig. 5 shows in the dotted curve a voltage wave having a high-frequency ripple placed to give a large error in the meter indication. This wave has seven maxima and seven minima per cycle. The irregular full line wave is the differential of the voltage and represents the condenser current. The time integral of the current wave between the zero points, *A* and *B*, corresponding to the positive and negative crest values of the voltage wave, is a measure of the crest value. This integral contains the positive areas *M*, *N*, *O* and *P* and the negative areas *T*, *U* and *V*. Theoretically, all current, both positive and negative, between the points *A* and *B* should pass through the meter and no current between the points *B* and *C* should pass through the meter. Reverse currents cannot pass through the valves, so that the meter will integrate all positive current area and neglect all negative area. At first sight it is evident that this will cause an appreciable error. Table I shows that in this extreme case the error is 26 per cent.

TABLE I

Showing comparison between correct time integral of the current wave of Fig. 5 as obtained with the rotating rectifier and the result obtained with hot cathode rectifier.

Area	With rotating rectifier		With hot cathode rectifier	
	+	—	+	—
M	0.40	....	0.40	....
T	....	0.22	....	....
N	2.54	....	2.54	....
U	....	0.00	....	....
O	0.74	....	0.74	....
V	....	0.25	....	....
P	0.44	....	0.44	....
Q	....	....	0.22	....
R	....	....	0.00	....
S	....	....	0.25	....
Sum	4.12	0.47	4.59	0.00
Net	3.65	....	4.59	....

Tooth ripples and resonant ripples, such as shown in the voltage wave of Fig. 5, are infrequent and can be entirely avoided by the use of proper means in the transformer circuits.

In careful tests on steady circuits of different wave shapes the indications of the spark gap, corrected for atmospheric conditions, have shown agreement and duplication of points to within 0.15 per cent. Such tests seem to indicate that the capacitance of the condenser terminals used is independent of the wave shape. The capacitance is, however, a function of the voltage and increases 4 or 5 per cent between low voltage and 25 per cent over voltage. This variation of condenser capacitance with voltage, however, causes no error, as it is taken care of by the instrument calibration.

The indications vary directly with frequency and proportional corrections can be made if the frequency varies from normal. If it is desirable to eliminate frequency corrections a calibrated shunt resistance to the meter M is used and adjusted to the indication given by the frequency meter. This complication is not justified, however, as frequency variations are infrequent and the correction when necessary is very simple.

Applications. The crest voltmeter has been found to fulfill all of the requirements of a practical instrument for dielectric testing, and for reading the crest value of pulsating and alternating voltage in the laboratory. Since its indications are a measure of the difference between maximum and minimum values of a periodic voltage wave, pulsating waves starting from zero can be read or unsymmetrical waves can be read if one of the crest values is known.

Summary

1. The crest voltmeter is a direct-reading instrument, reading either the r.m.s. value of a sine wave having the same crest as a high voltage wave to which it is connected, or the true crest value, depending upon its calibration.

2. The indications of the instrument are independent of atmospheric conditions and require no corrections except a proportional correction for variations from normal frequency.

3. The instrument is the equivalent of the sphere spark gap and derives its voltage from the high-tension circuit.

4. The indications are theoretically correct for all distorted waves having not more than one maximum and one minimum value per cycle, and practically accurate for all other commercial wave shapes to be found.

5. The instrument gives a continuous indication during the application and adjustment of voltage, instead of a limiting indication similar to that of the spark gap.

6. No preliminary setting with load disconnected need be made, as the voltage may be read under testing conditions.

7. The instrument is safe, convenient, and does not cause spark surges.

8. Tests with the spark gap in accordance with sections 531 and 532 of the Standardization Rules are impractical, inaccurate and destructive under certain conditions, while with the crest voltmeter all such tests can be practically and satisfactorily made.

9. The standard spark gaps should be the primary standard for calibration only, in accordance with section 534 of the rules, and the crest voltmeter or its equivalent should be used as a secondary and working standard.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 8, 1916.

(Subject to final revision for the Transactions.)

CREST VOLTMETERS

BY C. H. SHARP AND E. D. DOYLE

ABSTRACT OF PAPER

The paper shows how a voltmeter which will read directly the maximum or crest values obtained in high-voltage testing may be constituted by a combination of an electrostatic voltmeter and an electric valve. Diagrams of connection are shown and results of test given to indicate the validity of the method.

STRESSES in dielectrics subjected to alternating voltages are proportional to the maximum rather than the mean effective value of those voltages. The ordinary voltmeter which reads r.m.s. values is nevertheless the instrument ordinarily used in high-voltage testing, and the assumptions are made that the crest factor, that is, the ratio of the maximum to the r.m.s. value of the wave, is that corresponding to a sine wave, 1.41, and further, that it does not vary therefrom. These assumptions are made with the full knowledge that in the general case they cannot correspond strictly to the facts, but the lack of a suitable instrument for reading crest voltages has made it almost imperative to adopt this course. Quite apart from the ordinary deviations of the wave form of alternators from the sine curve, the variations in wave form with the load on the transformer which are encountered in high-voltage testing are often exceedingly serious and sufficient to introduce errors which are very important indeed; especially since they may be unknown and unsuspected. This renders highly desirable a suitable instrument for reading the crest values, and hence giving results independent of these variations.

As illustrations of some of the variations which occur in actual practise, Figs. 1, 2 and 3, all taken from different testing installations in practical use, are given, which with their captions are self-explanatory. Fig. 3 is particularly striking as showing a change in crest factor of 25 per cent with quite a small change in the load. It is evident that a condition such as indicated here was an intolerable one where, as was the case,

Manuscript of this paper was received January 13, 1916.

a product of great monetary value was being tested on the assumption that the wave was of sine form and invariable.

An instrument is available, and is recognized by the Standardization Rules of the A. I. E. E., whereby these maximum values may actually be measured. This is the spark gap, fitted either with needles or with spheres. Without going into detailed consideration of the shortcomings of the spark gap, it may be noted that it is deficient in that it can be set for one voltage only and gives no indications, except by breakdown, of the voltage to which it is subjected. It has been very aptly

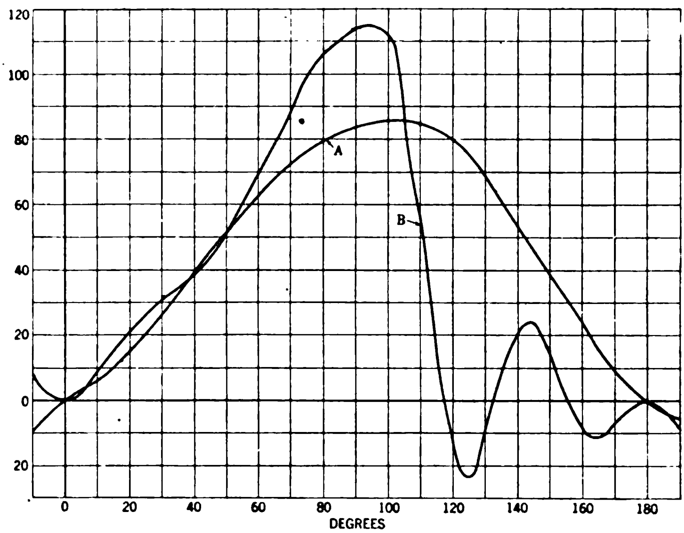


FIG. 1—WAVE FORM DISTORTIONS IN A TESTING TRANSFORMER INTRODUCED BY IMPROPER VOLTAGE CONTROL APPARATUS

A—Wave form of supply circuit.
B—Wave form of secondary of controller under load.

said that measuring voltages with a spark gap is like measuring current with a fuse. A spark gap can be used with accuracy only where it is placed at a sufficient distance from all extraneous bodies which might influence the character of the electrostatic field in the gap. The precautions required are outlined in the Standardization Rules. The breakdown value of the spark gap is also affected by the pressure and the relative humidity of the atmosphere. The variations due to humidity have not been standardized. The Standardization Rules say "If proper precautions are observed, the spark gap can be used to advantage in checking the calibration of voltmeters when

set up for the purpose of high-voltage tests of the insulation of machinery."

1. Sharp and Farmer[1] have described a crest voltmeter in which an instantaneous contact apparatus driven by a syn-

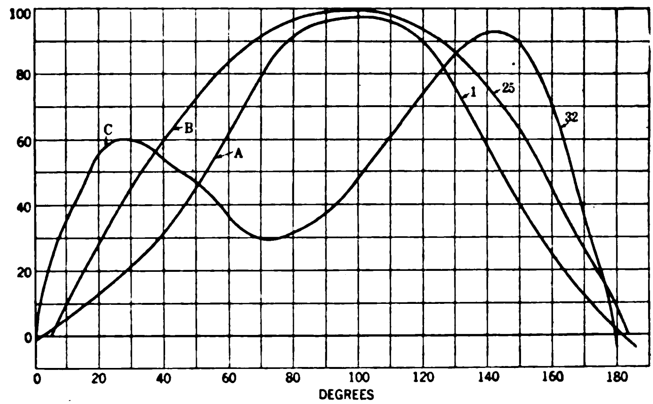


FIG. 2—WAVE FORM OF TESTING TRANSFORMER VOLTAGE

A—No load; crest factor = 1.11 × 1.41
B—Light load; crest factor = 0.98 × 1.41
C—Heavy load; crest factor = 1.15 × 1.41

chronous motor allows an electrostatic voltmeter to be put momentarily in contact with the high-voltage circuit at the crest of the wave. The voltmeter is thus charged up to the crest voltage and indicates this value. For steadying purposes a condenser is placed in parallel with the voltmeter. This

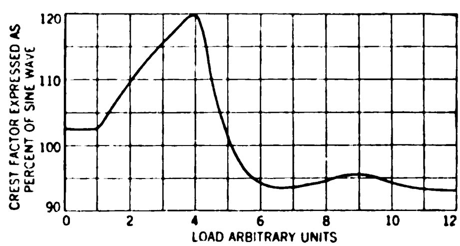


FIG. 3—VARIATION OF CREST FACTOR OF TESTING TRANSFORMER WITH LOAD CREST FACTOR EXPRESSED AS PERCENTAGE OF SINE WAVE VALUE

apparatus can be used on a condenser multiplier from the high-tension circuit or from voltmeter windings on the high-tension transformer, or from a calibrated step-down transformer. It suffers under disadvantages as follows:

1. TRANSACTIONS A. I. E. E., 1912, Vol. XXXI, part II, page 1617.

(*a*) A synchronous motor is required which must be started before measurements can be made, and which will not hunt.

(*b*) The maximum point of the wave must be found by shifting the contact device.

Inasmuch as the angular position of the maximum of the wave will vary as the wave form changes, it is necessary to follow up these shifts of the maximum point with changes in load. This is a troublesome thing to do, and unless it is carefully done, the indications of the instrument will be erroneous. This device has, however, the advantage that the crest voltmeter can be calibrated directly against an r.m.s. voltmeter in the primary circuit, provided the ratio of transformation of the transformer is known. This may be done as follows: With a transformer with a load at which its ratio of transformation is known and with a constant primary voltage of known value, the wave form of the secondary is traced, using the instantaneous contact maker and the electrostatic voltmeter in connection with its multiplier. In this use of the instrument, the method is that given years ago by Ryan. From this trace of the wave form, the r.m.s. value of the secondary voltage as given by the electrostatic voltmeter plus its multiplier is computed. By comparing the true r.m.s. value as given by the primary voltmeter and ratio of transformation with the indications of the electrostatic instrument and multiplier, the multiplying factor is obtained. This is the multiplying factor which must be applied to the crest reading.

2. Chubb and Fortescue[2] have given a method of reading crest voltage, which consists in putting a large air condenser on the high-voltage circuit and measuring the charging current of that condenser by means of a galvanometer which is short-circuited during each alternate half-cycle. Knowing the capacity of the condenser and the frequency of alternations, the measured charging current becomes a measure of the crest voltages.

3. Whitehead[3] has given a method similar to the above in which mercury arc-rectifiers are used in series with condensers and some form of ammeter. The connection of rectifiers is such that the ammeter is short-circuited during one-half cycle. This method obviates the synchronous motor.

2. TRANSACTIONS A. I. E. E., 1913, Vol. XXXII, part I, page 739.
3. A. I. E. E. PROCEEDINGS, June, 1914, page 920.

4. Lloyd, in 1912, in discussion of the paper of Sharp and Farmer, suggested that the oscillograph might be used as a peak voltmeter. The development of the oscillograph for this purpose has been described by Middleton and Dawes.[4] In this method the length of the band of light drawn out by the oscillograph element measures the crest voltage.

The purpose of the present paper is to describe connections whereby crest voltages can be read on an indicating instrument by a relatively simple apparatus. This method takes advantage of the properties of an electric valve in allowing current to pass in one direction and in stopping it in the other direction. If such a valve is placed in series with an electrostatic voltmeter, it is evident that the voltmeter must become charged to the maximum value of the waves and must retain that charge for a period of time depending upon the insulation of the voltmeter and the valve. The indications of the instrument will be independent of the frequency of the current and of the shape of the wave, except as to its crest value. While the mercury arc rectifier has manifest possibilities as a valve, the pure ionic discharge tube of Langmuir, to which the name "kenotron" has been given, is evidently the most available form of apparatus. Langmuir has shown that in these tubes of practically perfect vacuum, the discharge is absolutely unidirectional. The apparatus is of the simplest possible character and, with proper use, entirely free from any promise of quick deterioration. The only complication is that the cathode must be heated by current, but this is provided for in a very simple manner.

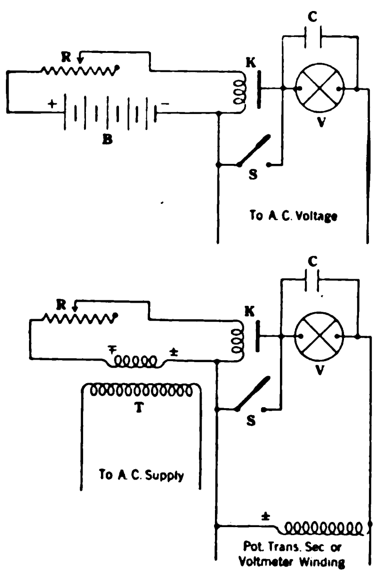


FIG. 4—DIAGRAM OF CONNECTIONS USED IN MEASURING CREST VOLTAGE

V–voltmeter; *C*–condenser; *K*–electric valve; *B*, *T*–heating battery and transformer; *S*–switch short-circuiting valve.

The electrical connections which have been used for this purpose are shown in Fig. 4. The upper half of the figure shows the filament of the kenotron excited by means of a battery of

4. A. I. E. E. PROCEEDINGS, June, 1914, page 1006.

a few cells. The lower connection shows it excited by alternating current taken from the same source as supplies the testing transformers and stepped down to the voltage of the filament. The second connection is evidently the preferable one, but cannot be used where the high-tension transformer is supplied from an individual alternator with field control of the voltage supplied to the high-tension transformer.

In the experiments here described, the voltmeter used was a pivoted one, directly indicating on a scale of volts and having

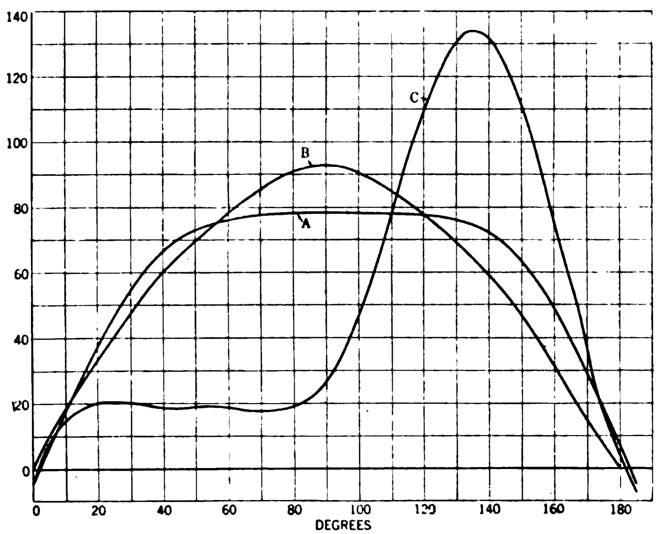


FIG. 5—BUILT-UP WAVES USED IN TESTING CREST VOLTMETER

Crest Factor by

Wave calculation from wave form		Wave meter and dynamometer voltmeter	Crest voltmeter
A	1.218	1.213	1.218
B	1.431	1.435	1.435
C	2.040	2.020	2.090

a capacitance of approximately 1.6×10^{-4} microfarad. In parallel with this is placed a capacitance of 0.02 microfarad or more. With a smaller capacitance in parallel, the leakage of the apparatus was sufficiently great so that the indications were no longer true indications of the crest value. In other words, a sufficient reservoir of charge must be used so that the leakage is a negligible factor. With this arrangement the charge is built up to the maximum value, if not in the first half-cycle then at least in the succeeding half-cycles. This

feature is important in the use of the instrument with a condenser or high-resistance multiplier, inasmuch as it enables the valve with its voltmeter to be put in parallel with a section of a high capacitance or high resistance carrying the high-voltage current, and the result obtained is independent of the actual value of capacitance or resistance used in the multiplier, depending only upon the ratio of the impedance of the portion of the multiplier about which the voltmeter is looped, to the total impedance. The capacitance of the voltmeter itself is eliminated because of the fact that it is retained in the state

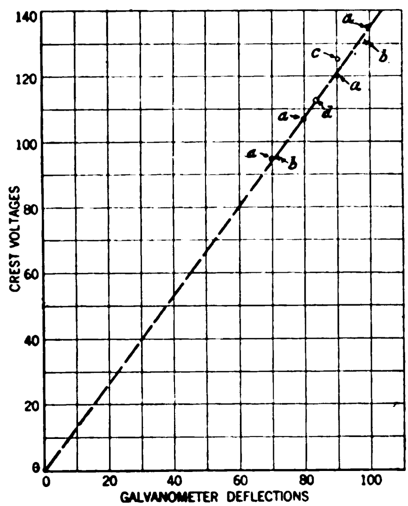


FIG. 6—SHOWS THE PROPORTIONALITY OF GALVANOMETER DEFLECTIONS TO CREST VOLTAGES

Points *a*	— 60-cycle	sine wave;	crest factor	= 1.41
" *b*	— 60 "	flat wave;	" "	= 1.30
Point *c*	— 25 "	peaked wave;	" "	= 1.56
" *d*	— 25 "	sine wave;	" "	= 1.41

of full charge, provided, of course, that the leakage is low. If the valve in series with the voltmeter is short-circuited, the voltmeter will read r.m.s. values; but these values will depend not only upon the above ratio but also upon the capacitance of the voltmeter as well.

If the apparatus is used directly on a step-down voltage transformer or on voltmeter coils without multiplier, the ratio of the reading of the voltmeter with the valve in series to its reading with the valve short-circuited will give at once the crest factor of the wave.

An important advantage is that the pointer of the voltmeter does not return at once when the voltage is removed. For instance, if the dielectric under test is punctured and the voltage drops, the reading of the voltmeter taken a moment after puncture has occurred will show the voltage which caused the puncture. Hence the voltmeter does not need to be watched so minutely during test as in the case when the indications follow directly any drop in the testing voltage.

This arrangement has been tested in a number of different ways, but the most important ones are summed up in the curves of Fig. 5, together with the appended table. Wave form A was built up from a sine wave fundamental plus a third harmonic; wave form B represents the fundamental alone, and wave form C represents a peaked wave built up from the third and fifth harmonics. The crest factors of the various waves were calculated from the wave forms as traced by a wave meter and were determined also by using a wave meter as a crest voltmeter and an ordinary voltmeter to give the r.m.s. values. These figures may be compared with the crest values as given by the valve voltmeter in which r.m.s. value was obtained by short-circuiting the valve. It will be seen that the degree of agreement is a very satisfactory one, indicating that with these wide variations of crest factor, the crest voltmeter gave true indications. The frequency was 60 cycles per second.

In a further series of tests the electrostatic voltmeter was replaced by a sensitive unipivot galvanometer in series with a resistance of one megohm, and in parallel with a condenser of one microfarad. The indications of the galvanometer were taken with frequencies of 25 and 60 cycles per second. In Fig. 6 is shown the relation between crest voltage as indicated by the electrostatic voltmeter plus the valve and the galvanometer plus condenser and valve. It will be seen that the relation between the two is practically a constant one, independent of the frequency of the current, which indicates that a galvanometer if looped about a sufficient capacitance may be used instead of the electrostatic instrument. Inasmuch as the latter instrument has, in some respects, less desirable characteristics than a galvanometer, particularly in respect to damping, the latter connection may be found in practise to be the more desirable one. The calibration of the latter arrangement, however, would be rather less direct than that of the former.

In conclusion it may be noted that the arrangement given offers possibilities in the matter of the study of surges. If it were connected through suitable transformers to a cable and a proper balance of valve capacity and capacitance were used, the apparatus might be adapted to trapping either a current or a voltage surge, and indicating the maximum value of the surge. With the capabilities of the arrangement for retaining its indication, it is probable the electrostatic voltmeter might be fitted to operate as an intermittent recorder, and so leave a record on a chart of the surges which have come in during a certain period of time or during the course of certain operations.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 8, 1916.

THE VOLTMETER COIL IN TESTING TRANSFORMERS

BY A. B. HENDRICKS, JR.

FOR EXACT determination of the high-tension voltage in testing transformers, an auxiliary winding of few turns placed on the same core and connected to an accurate voltmeter has been used with success.

This method was advocated and the construction explained some years ago,* but the idea seems to be generally misunderstood, the accuracy of the result obtained being often questioned.

For precise results at all loads and power factors, it is necessary and sufficient that the ratio of the flux linkages of the voltmeter coil and the high voltage winding be a constant.

The flux here considered is the resultant flux linked with the high voltage winding, or the main flux plus or minus the leakage flux combined vectorially.

With the coil so placed, the *IR* drop is the only sensible error. This is usually small, and owing to the vector relationship under ordinary loads is practically negligible.

It is not advisable to compensate for this by the position of the voltmeter coil, as the correction would be exact for one value of load and power factor only.

The impedance of the voltmeter coil itself may be neglected.

The accuracy of the method depends entirely on the design of the transformer and the location of the voltmeter coil, and can be made almost perfect.

Ordinarily, a dynamometer type of voltmeter is used, indicating effective values. If the maximum value is desired, a sine wave of potential must be employed or, the maximum determined by other means, such as an oscillograph.

It is suggested that much difficulty may be eliminated by the use of a true sine wave generator, and the avoidance of regulating devices and transformer characteristics liable to distort the wave.

Manuscript of this paper was received January 10, 1916.

*High-Tension Testing of Insulating Materials, A. B. Hendricks, Jr., TRANS. A. I. E. E. Vol. XXX, 1911.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 9, 1916.

OPERATION ON THE NORFOLK & WESTERN RAILWAY

BY F. E. WYNNE

ABSTRACT OF PAPER

This paper describes the great advantages, from an operating standpoint, incident to the inauguration of electric service on the Elkhorn grade of the Norfolk & Western Railway Co. and why it is possible almost to double the capacity of the road by the use of 12 electric locomotives, instead of the 33 Mallet locomotives formerly in service.

THE ELECTRIFIED portion of the Norfolk & Western Railway lies chiefly in southern West Virginia between Bluefield and Vivian, as shown in the map, Fig. 1.The distance by rail is 30 miles (48.2 km.) but, "as the crow flies," Vivian is only 18 miles (28.91 km.) from Bluefield. The approximate profile in condensed form is shown in Fig. 2. Curves from 8 deg. to 12 deg. are of common occurrence and the average curvature is over 3 deg. The maximum grades eastbound are 2 per cent against 2.36 per cent with the load. For westbound trains the maximum grades are 1.1 per cent against and 2 per cent with the load. These figures indicate the severity of the service so far as alignment and grades are concerned. With the exception of Elkhorn Tunnel, the entire line is double-tracked, with considerable third track, numerous spurs and cross-overs and several yards. At the summit of the long grade up the west slope is a 3000-ft. (914-m.) single-track tunnel, part of which is on a 3-deg. curve. On the east slope, just west of Bluestone Junction, is a 700-ft. (213-m.) tunnel over the westbound track only.

The principal tonnage is coal, a portion of which comes from points west of Vivian. Between Vivian and Coaldale, the adjacent hills are honeycombed with coal mines which furnish tonnage both east and west. In addition, coal from branch lines is brought to the electric zone at Eckman, North Fork, Lick Branch, Cooper, Bluestone Junction and Graham. Of course, time freight and passenger trains also pass over the electric zone. The gathering of tonnage trains of eastbound coal

Manuscript of this paper was received January 7, 1916.

throughout the field is naturally accompanied by the delivery of empty cars from westbound trains to the numerous mines. Between Vivian and Coaldale, the line is operated as an elongated yard without intermediate telegraph stations. Communication with the load dispatcher may be had by telephone at each westbound signal bridge.

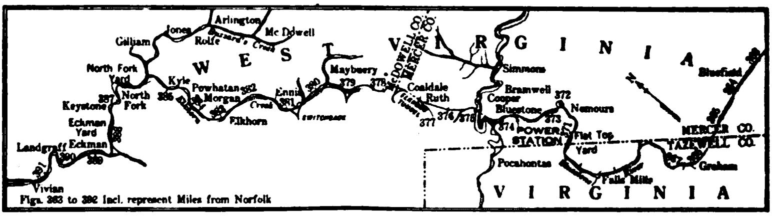


FIG. 1

The foregoing conditions apply with both steam and electric operation. In order fully to appreciate what electrification is accomplishing on the Norfolk & Western Railway, it is necessary to consider other general conditions which differ under steam and electric operation.

Until 1911, comparatively little coal was hauled west over the

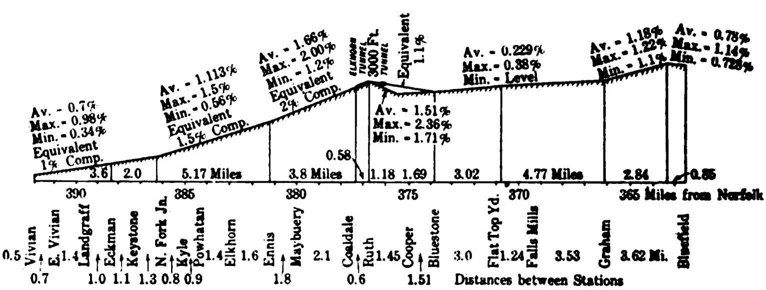
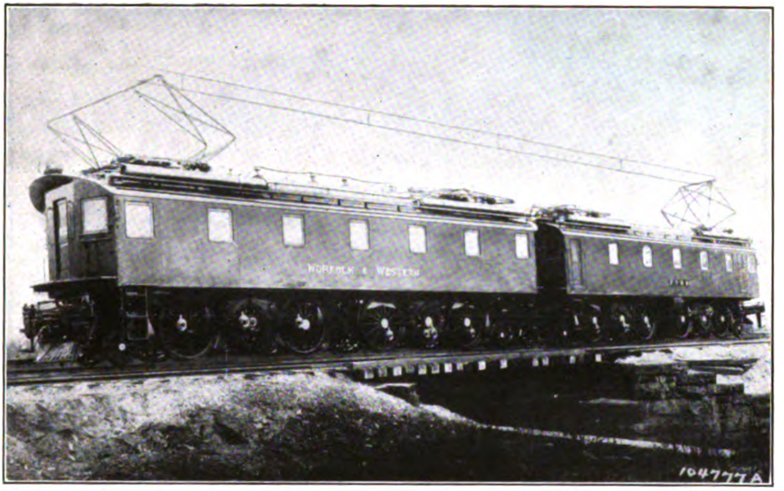


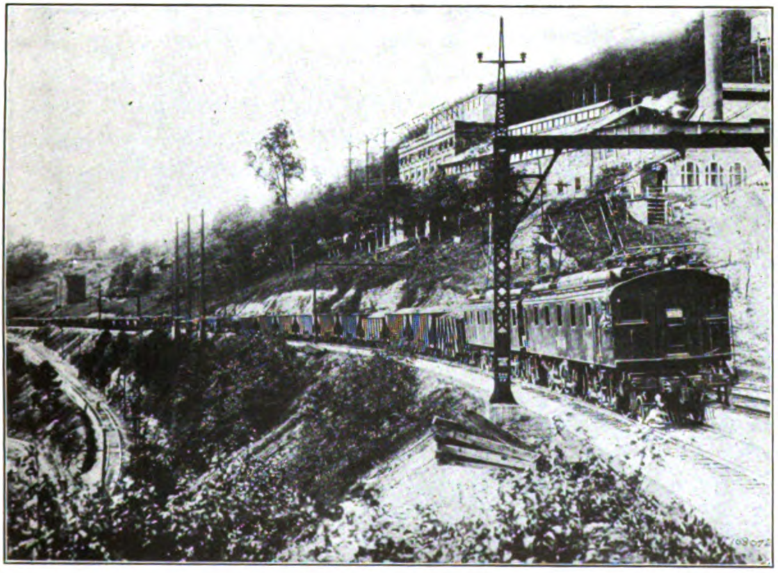
FIG. 2

hill. Eastbound coal constituted a decided majority of the total traffic. This was handled up Elkhorn Hill in 2360-ton trains with a Mallet locomotive, having eight driving axles, at the head end, a consolidation helper engine at the rear, and a consolidation pusher. Ordinarily the pusher locomotive did not work in the tunnel but remained with the train for emergency use. At Ruth, the east end of the long tunnel, the pusher cut off and returned west light or assisting in delivering empties on the west



[WYNNE]

FIG. 3—270-TON ELECTRIC LOCOMOTIVE USED ON NORFOLK AND WESTERN R.R.



[WYNNE]

FIG. 4—ELECTRIC LOCOMOTIVE AND COAL TRAIN ASCENDING GRADE AT SWITCHBACK

slope. From Ruth to Bluefield, the train was handled by the mallet and helper. On this part of the run, the helper was necessary only for assisting the train up Graham Hill. This assistance might have been given by a pusher operating between Graham and Bluefield only, but for the fact that the helper was required for delivering westbound empties and it was impracticable to hold locomotives for this purpose at Ruth or Coaldale between the time of helping an eastbound train up Elkhorn Hill and the time a westbound train of empties arrived.

Westbound, the Mallet and helper ran light or with a train of empties (sometimes amounting to 125 cars) and occasionally picked up at Flat Top a small number of westbound loads. Practically all of the switching, picking up loads and setting off empties was done by the consolidation engines. As much of the tonnage originated along Elkhorn Hill, some trains started with less than the rated tonnage and filled out at one or more points. When this was necessary and also when delivering empties, the train was held by the Mallet at its head. On rare occasions, the Mallet helped in filling out the train.

A number of difficulties were experienced with steam operation. In starting on the hills, the rear engines, with steam in the cylinders, held the train until the head engine got its portion of the train under way. This period of standing under load ran from 30 or 40 seconds up to two or three minutes and often was repeated a number of times before the train got started. As the locomotives were rated practically at their maximum tonnage with good rail, slipping was a frequent occurrence when any condition reduced the adhesion. The slipping of either consolidation or one truck of the Mallet caused a loss of one-fourth of the motive power on the train.

On the west slope, eastbound locomotives took coal and water at two points, one of which was at times the starting point. Another stop for water was made at Cooper or Flat Top. The delays due to this were in themselves considerable, since at each coal or water station either two or three engines had to be cut off from the train and handled separately, the train being pulled up in the interval between supplying the head and rear engines. The attendant delays due to congestion were even more serious. At times, three or four trains followed each other closely, resulting in a delay at coal and water stations of about two hours for the last train of the fleet. Frequently further delays were encountered, because by the time the third or fourth train was coaled

and watered, it was necessary to clear the main line for one or more superior trains.

The low speed on grades with steam locomotives was another feature making operation difficult. On the heavy part of the grade from Ennis to Ruth the speed seldom exceeded six miles (9.6 km.) per hour and was often as low as four miles (6.4 km.) per hour. The fastest time freight was scheduled at only 9.5 miles (15.2 km.) per hour from Vivian to Coaldale and 13.3 (21.4 km.) miles per hour from Coaldale to Graham, while the fastest passenger train had a schedule of 19.5 miles (31.3 km.) per hour from North Fork to Coaldale.

The Elkhorn Tunnel was, to say the least, an unpleasant feature of steam operation, the grade being such as to require both the Mallet and helper to work through it going east. Although it was ventilated by fans blowing in the west end and the train speed was low, considerable smoke and gas were still in the tunnel when the helper and pusher went through. A little imagination can picture the conditions when a train stopped in the tunnel and all three engines had to work to start it.

Under the foregoing conditions, the maximum number of freight cars handled up Elkhorn Hill in one month was approximately 17,000. The average time of a round trip between Bluefield and the coal fields was 12 hours, and this constituted a day's work for the train crew.

Between 1911 and the time of electrification, additional Mallets with arches, superheaters and stokers were applied in this service and larger three-engine trains with Mallets in each position were operated. This afforded some relief, but 33 Mallets were required to handle the traffic in this way.

In 1911, no consideration was given to the electric operation of time freight and passenger trains. Now, in addition to handling coal trains and empties, the electric locomotives are pushing all eastbound time freights to Ruth and two of the heaviest eastbound passenger trains to Bluestone Junction.

One electric locomotive at the head and one electric pusher take trains of 3250 tons east to Ruth where the pusher cuts off and returns west light or assists in delivering empties. From Ruth to Flat Top, the head engine alone suffices. At Flat Top, the train is filled out to 4700 tons and an electric pusher is attached to assist the train to Bluefield. A regular day's work for a head crew is to take a train of empties from Bluefield to the west slope, return with loads to Flat Top, then run west light,

with empties or with west loads to the coal fields and return with loads to Bluefield. An Elkhorn pusher crew frequently handles five or six eastbound trains as a day's work, while a Flat Top pusher at times exceeds this on account of the shorter distance. With the electric locomotives, gathering loads and delivering empties may be accomplished equally well by either the head or rear locomotive.

On account of the length of train and curvature of the track, it is at times impossible to hear whistle signals. In starting a train with two engines, other means of signaling are used. The head locomotive releases brakes and lets the slack run back. As soon as the engineman on the pusher feels the blow resulting from this, he applies power and holds the train until the head engineman has applied power and gotten the front portion of the train sufficiently under way to permit motion of the rear locomotive and its share of the load. The period of standstill with power on for the pusher engine with this method of operation rarely exceeds 30 seconds and generally a satisfactory start is secured on the first attempt. This speaks well for the smoothness of the electric control, as the electric locomotives have less weight on drivers per ton of trailing load handled than was the case with steam locomotives. When slipping does occur on one truck, the loss of motive power is only one eighth of the total or one half of the proportion which occurred with steam.

The delays for taking coal and water have been eliminated from the trains which are operated entirely with electric engines, and have been reduced on those trains which are only pushed electrically. Consequently, there is also a great reduction in the time lost in secondary delays which were formerly produced by coaling and watering.

By means of pole changing, the electric locomotives are arranged for two speeds. The 14-mile (22.5 km.) per hour speed is used regularly for the heavy freight work, while the higher speed of 28 miles (45 km.) per hour is used for passenger trains, light engine movements and a certain amount of time freight operation. As a result, the speed of the coal trains has been more than doubled on the heavy grades and the average running speed for eastbound loads over the entire trip from the coal fields to Bluefield has been increased over 50 per cent. In passenger service, it is a common occurrence to pick up a train 20 minutes late at North Fork and put it into Bluestone Junction on time.

The dangers of steam operation in Elkhorn Tunnel have

practically been eliminated. The majority of the trains passing through this tunnel have only electric locomotives attached. Nearly all of those which do have steam engines on them are pushed through by the electrics at not less than 14 miles (22.5 km.) per hour with the steam locomotives doing very little work. How satisfactorily this is accomplished is indicated by the fact that in assisting time freights with a steam locomotive on each end, the head engine working and the rear engine idle, the electric pusher works through the tunnel with its windows open and without noticeable smoke or gas in the electric cab.

Certain features of the locomotives are notable in their effect on the handling of trains. The control is extremely flexible. Power may be applied to the motors of one truck on each half of the locomotive in starting. This is particularly advantageous with a light engine or a train of empty cars. In changing the speed, one half of the motors are changed at a time so that the entire tractive effort of one locomotive is never lost.

The arrangement for operating the rheostats is such that practically an infinite number of steps is provided for acceleration. The effect of unequal wheel diameters in unbalancing the loads on different motors may be readily counteracted. In case of wheels slipping, the load on the slipping drivers may be reduced until they again grip the rails, without reduction in the tractive effort developed at the drivers which are not slipping. In case of trouble, either a single truck or a half engine may be cut out without affecting the operation of the remainder of the locomotive.

The inherent regenerating feature is of great value in controlling the trains on down grades, and the fact that the speed down grade is constant and inflexible prevents the possibility of surges in the train which would result in broken draw-heads.

Considerable assistance in effecting a smooth stop is secured with trains having two locomotives approximately one-half mile apart by passing the load from locomotive to locomotive while backing off the control. To be a little more specific, when the head engineman desires to make a stop, he introduces a portion of the rheostat into the circuit of his motors. This slightly reduces the speed of the head engine and throws additional load on the rear locomotive. The latter, noticing the increase of load, realizes that a stop is about to be made and he too starts inserting resistance into his motor circuits, always, however, keeping his tractive effort up near the maximum. The front

engineman, on the other hand, inserts his resistance more rapidly, reducing the speed of his engine at a slightly greater rate than the rear engineman and allowing the latter to "bunch" all the slack in the train. As soon as the slack has all been bunched, the head engineman shuts off and if necessary makes a slight reduction with his automatic brake to bring the train to a stop. The rear engineman in his turn introduces more and more resistance into his motor circuits to keep from overloading his motors, until flush level has been reached. When he gets to this point, he holds his resistance constant until the train has been brought to a dead stop. He then makes a 30-lb. or 40-lb. application with his independent brake and having done this, throws his master controller to the off position.

Since electrification, not only has the eastbound traffic been very heavy but the westbound traffic from Flat Top is comparatively great when referred to that of 1911. Complete operating data are not available for publication at this time. However, a few general figures derived from the performance since the first of June, 1915, will serve to indicate what electrification is accomplishing. Compared with the Mallet locomotive performance of 1911, the despatcher's reports show that the electric locomotives are making eight times as many miles per train-minute delay due to locomotive failures in service. They further show that the electric locomotives have handled up Elkhorn Hill in a single day 50 per cent more slow freight tonnage than was handled by steam locomotives in the maximum day recorded prior to the summer of 1911. This was done with only nine of the twelve electric engines in service. From Nov. 1st to Dec. 17th, inclusive, there was no delay due to failure of electric locomotives in service. During this period the electric locomotives made nearly 45,000 miles (72,420 km.) with approximately 700 freight trains and 25,000 freight cars, each of from 60,000 to 180,000 lb. (27,215 to 81,646 kg.) capacity, eastbound up Elkhorn Hill. In addition, they pushed an average of two passenger trains per day up the hill and cared for an unknown quantity of switching service and westbound freight traffic. Presumably, the railway company will at some time in the future give statistics showing, better than is now possible, the heavy traffic and severe service which electrification is successfully meeting in this installation.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 9, 1916.

CHATTERING WHEEL SLIP IN ELECTRIC MOTIVE POWER

BY G. M. EATON

ABSTRACT OF PAPER

The paper shows that chattering wheel slip is characteristic of all types of electric motive power. The application of the motive power in the electric and steam drives is compared, and the reasons for the chattering wheel slip and the means of measuring and rectifying the same are given.

WHEN THE steam pressure in the cylinders of steam motive power is high enough to start slipping of drive wheels, their acceleration is fairly uniform and rapid, the load on the piston being well sustained on account of late cut-off and stored steam in pipes, receivers, etc.

In contrast to this, with electric motive power, regardless of the method of transmitting the tractive effort from the rotors to the wheels, the acceleration after slipping starts is liable to be erratic, being dependent upon the distribution of rotating masses, and upon the characteristic of the coefficient of friction between wheel and rail.

The fundamental difference between the running gear of steam and electric motive power is that in the steam locomotive, the only moving parts having relatively high moment of inertia are the driving wheels.

In an electric locomotive, the moment of inertia of the rotors, especially when operating through a gear reduction, may be as great as or greater than that of the driving wheels.

The combined inertia of connecting rods, cross-heads, piston rods and pistons is practically negligible as far as it affects acceleration of driving wheels after slipping starts. In an electric locomotive, when slipping occurs, the sequence of events is as follows, regardless of the type of drive:

Current is applied to the motor and the rotor starts to turn. Clearances in the entire transmission mechanism are first eliminated. Then, as the torque is increased, the metal of the

Manuscript of this paper was received December 31, 1915.

transmission, framing, etc., is bent and twisted, or otherwise deflected. This stressed metal becomes a storage battery of energy. Finally the tractive effort reaches a value sufficient to overcome the existing adhesion at the rail (coefficient of friction of repose), and the wheel starts to slip. The instant relative movement occurs between wheel and rail, the coefficient of friction drops from that of repose to that of relative motion. There is, therefore, an opportunity for the stressed metal to start discharging its stored energy, since part of the resisting force has disappeared. This energy is expended in accelerating the wheels ahead of the angular position they occupied relative to the rotor at the instant slipping started.

It is necessary next to analyze independently the two divisions of the rotating system, namely, rotors and wheels.

Since the wheels are being accelerated ahead of the rotors, the rotors are losing their load and will tend to speed up. This is true not only of motors of series characteristic, but also of induction motors when running below synchronism, as will ordinarily be the case in traction work when the wheels slip. In fact, the induction motors, because their generated counter e. m. f. with increased speed is less than with series motors, will hold up their torque better and, therefore, accelerate faster. The induction motor, in this particular, more nearly approaches the steam locomotive, in which, at starting, steam is cut off as late as possible in the stroke, so as to get the maximum starting tractive effort.

Analyzing next the other division of the system, the adhesion at the rail will decrease as the velocity of the wheel tread relative to the rail, increases. The effort being transmitted through the transmission system, however, will decrease very rapidly, due to expenditure of stored energy, and as soon as this effort, which is tending to accelerate the wheels, becomes less than the adhesion at the rail, which is tending to retard the wheels, the wheels will evidently start to slow down.

There are, then, two sets of rotating masses mechanically coupled, the masses at one end of the system accelerating, and those at the other end, retarding. As soon as clearances in the transmission are taken up, there is liable to be a jolt on the mechanical system, accompanied by a recoil. This gives the setting for chattering action, and such action has been experienced in practically every type of electrically-driven rolling stock where the motors are sufficiently powerful to slip the wheels at high adhesion.

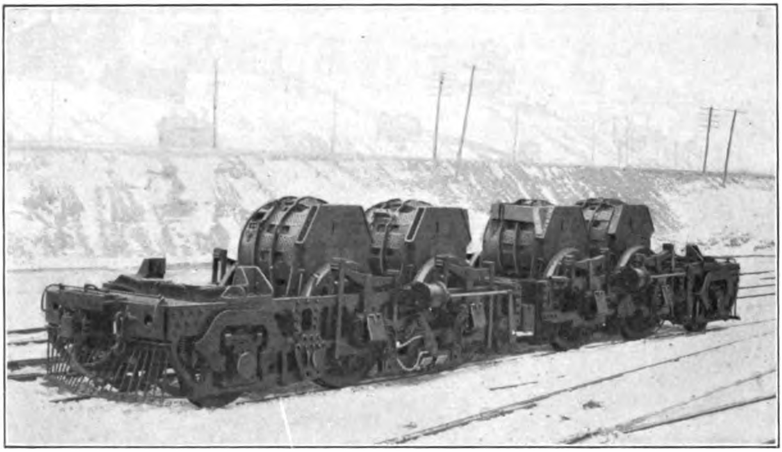


FIG. 1 [EATON]

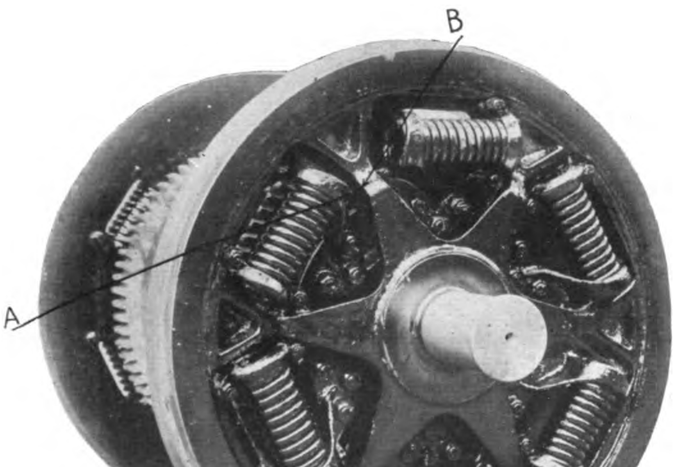


FIG. 2 [EATON]

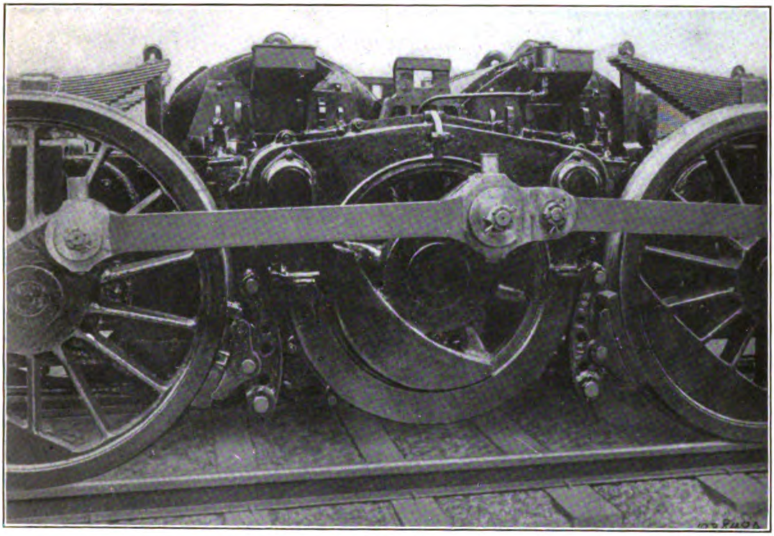


FIG. 3 [EATON]

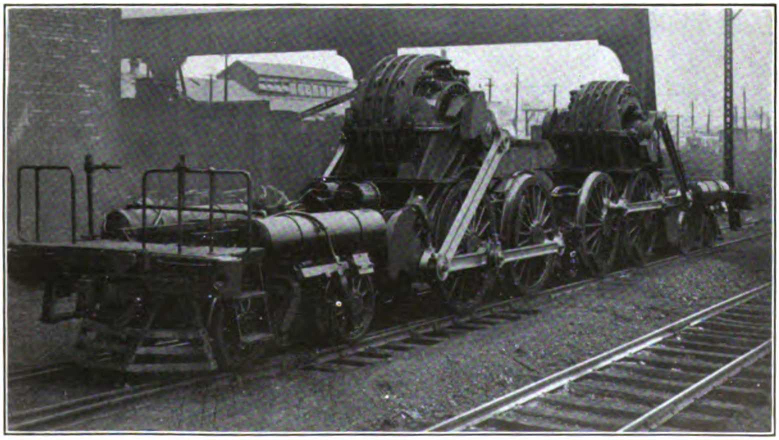


FIG. 4 [EATON]

This occurred on the geared freight and passenger locomotives whose transmission is shown in Fig. 1. The quill arms at the point marked *A* hit against the wheel spokes at the point marked *B*, Fig. 2, and more or less breakage of these arms occurred. It was found, however, that the arms which broke had blow-holes in the interior of the castings, and after these defective castings were eliminated, the breakage practically ceased.

In later locomotives in the same service equipped with two motors per axle, the change in armature inertia eliminated this striking. Chattering slip still occurred, but the capacity of the quill springs was sufficient to limit the amplitude of swing to a distance less than the existing clearances.

A certain amount of similar striking again occurred in some switching locomotives, but here again the parts were strong enough to stand the service.

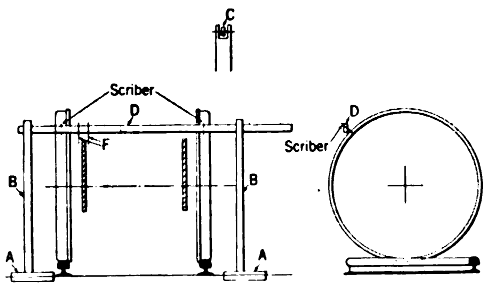


FIG. 5—HAND-OPERATED DEVICES FOR RECORDING CHATTERING SLIP

The same characteristic is occasionally observed in city and interurban cars, although this is much less frequent than in heavy hauling electric locomotives. This is due to the greater tractive power in proportion to the weight which is employed in the latter type of motive power.

In case of freight locomotives where the motors are geared directly to the axles the same phenomenon has been observed.

On the Norfolk and Western locomotives, chattering slip occurred in the running gear shown in Fig. 3. After the locomotives had been in service for some months, evidences of failure were detected in the crank pins. The cause was traced to chattering slip by means of a rough oscillograph, as shown in Fig. 5. The brakes were set on three trucks, and the oscillograph frame was set up on the fourth truck. The wheel tread was chalked. The oscillograph frame was oscillated about its sup-

porting points *A*, Fig. 5, the amplitude of oscillation being two inches. The time of complete oscillation was two seconds. The scribers were pressed against the wheel tread. The wheel treads were then slipped, and the characteristic diagram of the chattering slip was obtained, as shown in Fig. 6. The analysis in the figure is self-explanatory. By means of this diagram, it was possible to figure approximately the forces necessary to produce the acceleration and retardation which occurred, and the resultant stresses in the rods, pins, etc., were calculated.

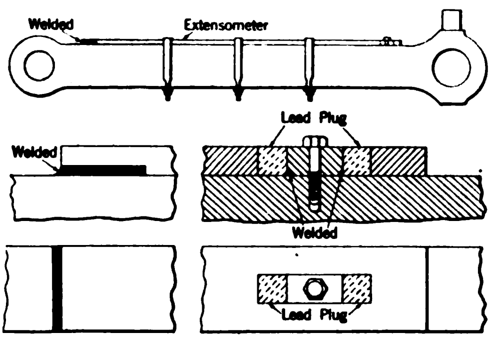


FIG. 7

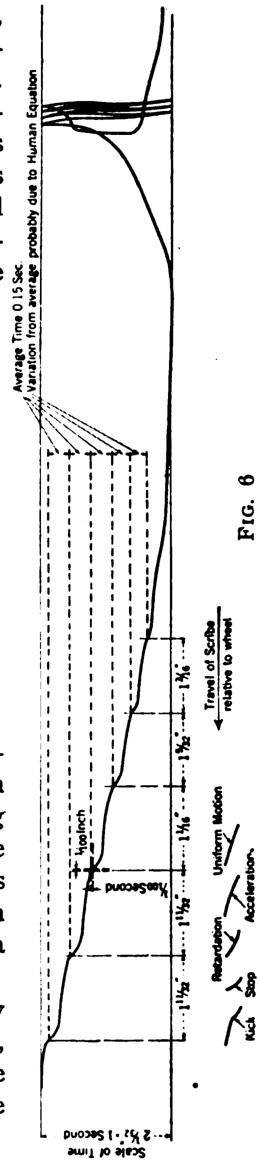


FIG. 6

To check the oscillograph figures, extensometers were arranged, as shown in Fig. 7, by means of which the connecting rods indicated their own stresses. The extension and compression of the rods were recorded by means of the compression of blocks of lead. This is evident from a little study of the figure.

The two methods checked within a very few per cent. On the basis of the results, new rods, pins, etc., were applied on the locomotives. These have proved adequate for the service.

This chattering slip was more evident on the Norfolk and Western locomotives than could have been anticipated, since this was the first time electric haulage had been

applied in service where such extremely high tractive efforts were required.

The phenomenon had never been observed on the locomotives with transmission as shown in Fig. 4. After it was experienced on the Norfolk and Western, however, permission was secured to make a test on the locomotives shown in Fig. 4. The wheels were slipped several times in succession in the same spot on the rails, and on the third slip, chattering occurred.

In all heavy hauling electric motive power, this problem must be considered, with every type of drive. The great number of variables entering and the wide fluctuation of certain of these variables render broad experience necessary in securing a successful solution of the problem. This has been gone into deeply and quantitatively by the writer and his associates, together with engineers of the locomotive works, with elaborate special testing apparatus, but it has been considered necessary to eliminate all quantitative values from this brief paper.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers. New York, February 9, 1916.

THE LIQUID RHEOSTAT IN LOCOMOTIVE SERVICE

BY A. J. HALL

ABSTRACT OF PAPER

This paper describes the liquid rheostat in locomotive service, giving in detail the arrangement of the mechanical parts and means for controlling it.

LIQUID rheostats in locomotive service were successfully used for the first time in this country to control three-phase induction motors on the Norfolk & Western locomotives, which have certain operating characteristics resembling very closely those of the steam locomotive, especially the manipulation and the amount of abuse they will stand without being materially damaged.

The principal functions required of these rheostats are as follows: To cut out the resistance in the secondary circuit of the main motors while accelerating, or regenerating; to compensate for the slip between the different pairs of motors, due to the variation in the size of drivers, and to make and break the current in the main circuit to reduce wear on the primary switches.

The main circuit schematic diagram, showing the connections of the liquid rheostat in conjunction with the rest of the equipment is shown in Fig. 1.

The rheostats are operated in pairs each pair having one operating mechanism, storage reservoir, cooling tower and circulating pump.

Figs. 2, 3 and 4 show the mechanical structure of the liquid rheostat, which consists of one main casting, which is divided into four compartments, a central one and three arranged in triangular form around it. A set of electrodes is mounted in each of the three outer compartments. In each compartment, one electrode is grounded to the side of the main casting, and the other is suspended from the top cover and insulated from ground by three porcelain insulators. The rods which support the latter electrode are connected by copper straps on the outside

Manuscript of this paper was received January 7, 1916.

of the cover. Each set of electrodes is connected through a pole change-over switch to the secondary of a three-phase motor. The electrolytes furnishes resistance between the insulated electrodes suspended from the cover, and those grounded on the side of the main casting, thus making the main casting the common point of the star connection. The center compartment provides space in which a steel tube, *T* (Fig. 3), which can be raised or lowered, acts as an overflow pipe for the liquid. The height of the liquid in the rheostat is thus varied by the position of the overflow tube. The electrodes are made up of iron plates.

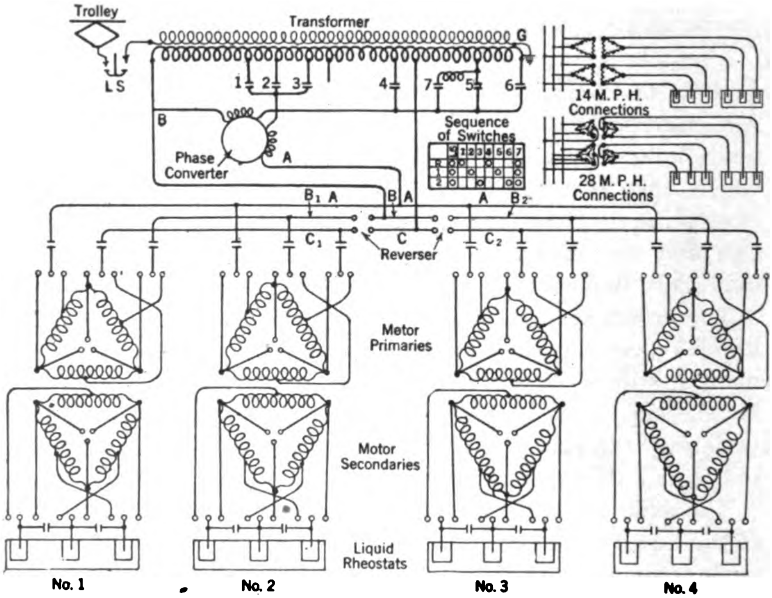


FIG. 1—SCHEMATIC DIAGRAM OF MAIN CIRCUITS OF SINGLE-PHASE LOCOMOTIVE WITH LIQUID RHEOSTAT CONTROL FOR INDUCTION MOTORS

The effective area gradually increases and the resistance in the circuit decreases as the surface of the liquid arises.

Two of these rheostats are mounted on top of the main supply tank containing the electrolyte, which consists of a 0.5 to 1 per cent solution of anhydrous sodium carbonate (NA_2 CO_3). The intake to a pump which will circulate approximately 300 gallons (1135 l.) per minute is connected to the supply tank and the outlet is divided into two paths which lead into the bottom of the rheostat castings mounted on top of the supply tank. The upper portion of the regulating or overflow tube (*T*) is about three in.

(7.6 cm.) smaller in diameter than the lower portion, so that when this tube is at its lowest position, there is a space (S) around the valve for the liquid to flow through from the rheostat to the supply tank without coming into contact with the electrode. When the overflow tube is raised, the upper portion of the larger part of the tube comes in contact with the valve seat, preventing the liquid from flowing through. It then flows over the top of the tube, raising the level of the electrolyte in the rheostat and

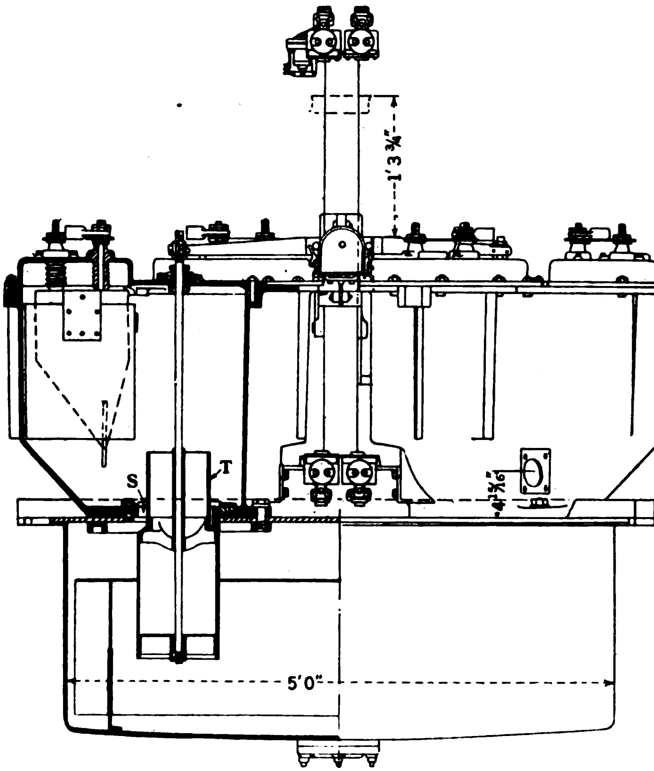


FIG. 3—PARTIAL SECTION OF LIQUID RHEOSTAT

submerging a portion of the electrodes. This position is called the " flush-level " of the rheostat.

The operating mechanism in the center of the rheostat is controlled by a balanced pressure operating mechanism which is mounted above and between the two rheostats. The crossarm extending from this mechanism is connected to each of the two overflow tubes by a rod. Thus the raising or the lowering of this crossarm raises or lowers the level of the liquid, which in turn

varies the surface of the electrodes submerged. The entire control of the locomotive centers about the liquid rheostats, which are so designed that the engineman can bring his locomotive up to speed with practically an infinite number of steps.

The master controller, Fig. 5, consists of two separate and independently operated drums, neither of which is mechanically interlocked with the other, but both are interlocked with the reverse drum, so that both handles must be in the "off" position before the reverse drum can be thrown. The speed drum has four "on" positions to set up the required combination of pole change-over drums, reverser and primary switches. The two main positions are the 14-mi. (22.5-km.) per hr. and the 28-mi. (45-km.) per hour. Between the 14-mi. (22.5-km.)

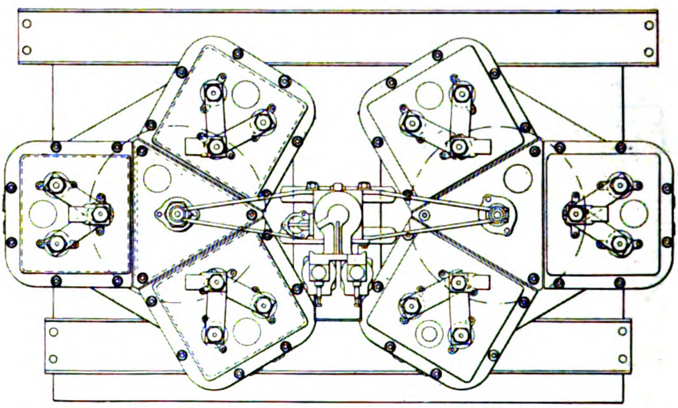
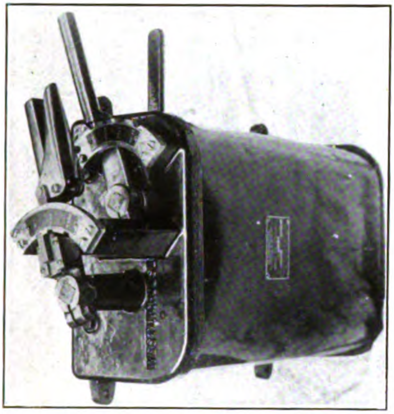


Fig. 4—Sketch Showing Horizontal Arrangement of Rheostat Tanks

per hr. and the "off" position, there is a notch which will give a 14-mi. (22.5-km.) per hr. combination on one truck only in each unit. This position is useful for handling a light engine, switching, or starting up a long train of empties. The other position is between the 14 and 28 mi. per hr. combination. This is for changing over from 14 to 28 mi. per hr. without losing tractive effort or causing sudden jolts in the train while changing over. The transition is made by first changing over one pair of motors in each unit to 28 mi. per hr., and as soon as the rheostat for these motors has reached the flush level position on the 28-mi. per hr. combination, the speed handle is moved to the full 28-mi. per hr. position, which will thus change over the remaining pair of motors.

The accelerating drum has three operating positions, marked



[HALL]

FIG. 5—THE MASTER CONTROLLER

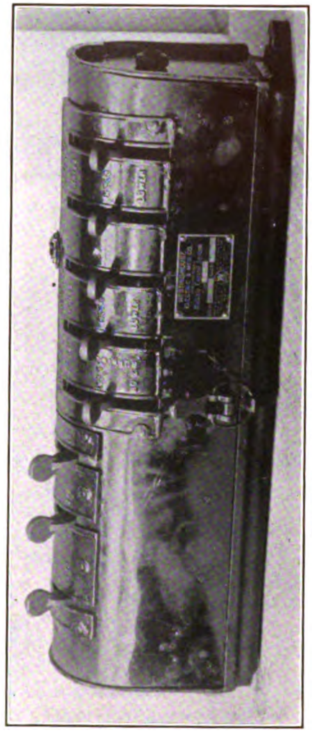


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FIG. 6—AUXILIARY CONTROLLER

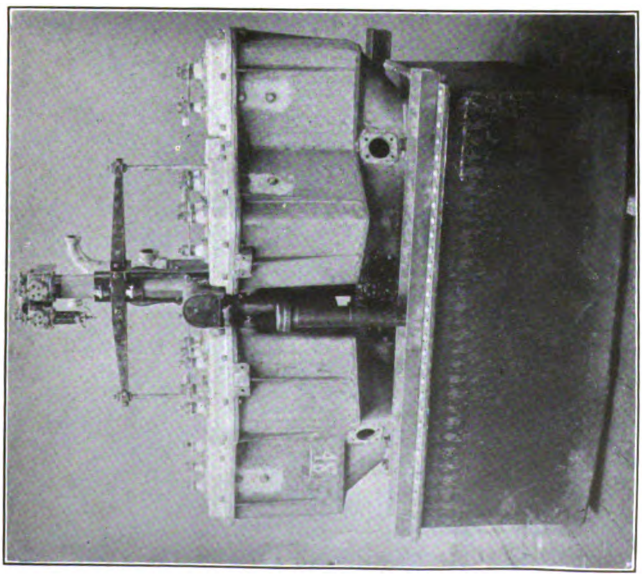

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FIG. 2—THE LIQUID RHEOSTAT

"lower," "hold," and "raise." These terms refer to the level of the liquid in the rheostat.

In addition to the master controller, an auxiliary controller, Fig. 6, is provided, in which are located levers for the control of the pantagraph, phase converter, etc., and a set of levers by means of which the load on each pair of motors may be governed independently. This independent control is provided so that any difference of load between the various trucks may be corrected, such as that due to difference in wheel diameter, variation in electrolyte, etc. It is also advantageous in the event of one truck slipping its wheels. When this occurs, the torque on this truck can be reduced until the wheels again catch the rail. It can then readily be brought back to full torque without reducing the torque of the remaining drivers.

When the rheostats are full of liquid, the proper short-circuiting switches are closed, short-circuiting the motor secondaries. These short-circuiting switches do not come in until the operating mechanism is in the full "on" position.

Two limit switches are used, one for each speed combination, their function being similar to an overload trip, except that they do not open the main circuit. Should the torque exceed a predetermined amount, the limit switch will open the control circuit of the liquid rheostat operating mechanism, and thus lower the level of the electrolyte, inserting more resistance in the secondary of the motor. These limit switches are especially useful for preventing the motors on the rear locomotive from being overloaded when the train is being brought to a stop.

The cooling tower for electrolyte consists of a series of inclined trays, the liquid flowing over the trays while air is blown over the surface of the liquid to dissipate heat by vaporization. A supply pipe for the cooling tower is connected to the main circulating system near the outlet of the pump. This will by-pass a certain amount of liquid which, after flowing over the surface of the trays, flows back into the supply tank.

The cooling tower operates whenever the locomotive is in service; the rate of cooling varies according to the temperature of the liquid—the hotter the liquid, the more effective the cooling tower becomes.

The results obtained in this severe service, in flexibility of control, capacity and ability to withstand extraordinary duty, have demonstrated conclusively the advantage of this method of control.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 9, 1916.

A METHOD OF DETERMINING THE CORRECTNESS OF POLYPHASE WATTMETER CONNECTIONS

BY W. B. KOUWENHOVEN

ABSTRACT OF PAPER

The object of this paper is to describe a method of checking the correctness of the connections of a polyphase watt-hour meter on a three-phase circuit; and to show that the methods most commonly used for this purpose are unreliable. Polyphase wattmeters are classified according to the number of their voltage terminals and expressions giving the amount of energy theoretically registered by the meter are derived for all possible arrangements of the connections for each class. The correctness of these expressions was checked experimentally. The expressions are given in the form of tables. A study of these tables reveals the fact that the methods of checking the connections in most common use are unreliable. A method is developed which may be relied upon to check the correctness of the meter connections on a balanced three-phase circuit at any power factor. Rules are worked out from this method, that make the rectification of incorrect connections simple. In addition to this, another method is described which may be used on balanced or unbalanced three-phase circuits atany power factor, provided the opening of one phase at a time is permissible.

THIS PAPER describes a method for ascertaining the correctness of the connections of a polyphase wattmeter on a three-phase circuit.

The accurate measurement of electric power is very important, and on three-phase circuits polyphase wattmeters have come into general use for this purpose. The liability of making mistakes in the connections when installing these meters is well known and several methods of checking the connections are in use. Articles on this subject have appeared in the *Electric Journal** and in other publications, and the National Electric Light Association devotes several pages of its handbook to a description of methods for checking the connections. A canvass of some thirty power companies throughout the country brought out the fact that almost the only method of checking the connections in actual use is that of opening the voltage or current supply of each element of the meter in turn and noting the direc-

* See Bibliography at end of paper.

Manuscript of this paper was received December 10, 1915.

tion of rotation. This should be in the right direction if the power factor is above 0.5. However, not only is the above check unreliable, but also none of the other simple checks in use may be completely relied upon in identifying the correctness of the connections. It is possible for the meter to satisfy these checks and still be incorrectly connected. For this reason the writer undertook the study of the connections of a polyphase wattmeter.

A study of all the possible arrangements of the connections was made, and the direction and rate of rotation of the disk was determined theoretically for each arrangement. The theoretical results were also checked experimentally. A simple method of checking the correctness of the connections of a polyphase meter on a three-phase balanced circuit at any power factor was developed from the results.[1] The assumption of a balanced load is justified by the fact that every customer requiring a polyphase wattmeter has at least one three-phase motor. Although the discussion is confined to watt-hour meters, the results apply equally well to other similar meters.

The Investigation

It is a well-known fact that a polyphase watt-hour meter consists of two separate single-phase elements acting upon a common shaft. Each element is provided with separate current and usually separate voltage terminals, and for the purpose of this investigation the meters are classified according to the number of voltage terminals provided.

Class A contains those meters which have two voltage terminals for each voltage coil, or four voltage terminals in all. Meters of this class may be used with or without voltage transformers.

Class B contains those meters which have but three voltage terminals. On these meters the ends of the voltage coils that are at the same potential are connected together and brought out to a common terminal. This class of meters may also be used with or without voltage transformers.

Often in practise, especially when potential transformers are used, the two voltage terminals of a Class A meter that are at the same potential are connected together. In such cases meters

1. After the completion of the paper the writer learned that the method developed is not new. However, no mention of it was found in technical publications.

with four voltage terminals belong to the Class B type of instruments.

Class C contains those meters which have but one voltage terminal. This terminal is the common terminal referred to in Class B. In Class C meters the other end of each voltage coil is connected to one end of the corresponding current coil and brought out to a single terminal. Meters belonging to this class cannot be used with either voltage or current transformers and are usually of the house type.

The number of possible arrangements of the connections is different for each class and therefore each class was considered separately. The number of different arrangements of the voltage connections is given by the expression

$$y = \underline{|x}$$

where x is the number of voltage terminals of the meter and y the number of different arrangements of the connections to these terminals possible. For each arrangement of the voltage terminals, there are sixteen arrangements or combinations that may be formed by the current connections and by the opening of the voltage leads. These are as follows:

(a) Phase I and phase II connected correctly
(b) Phase I reversed, phase II correct
(c) Phase I correct, phase II reversed
(d) Phase I and phase II reversed
(e) Phase I and phase II correct, voltage lead 1 open
(f) Phase I and phase II correct, voltage lead 2 open
(g) Phase I and phase II correct, voltage lead 3 open
(h) Phase I reversed, phase II correct, voltage lead 1 open
(i) Phase I reversed, phase II correct, voltage lead 2 open
(j) Phase I reversed, phase II correct, voltage lead 3 open
(k) Phase I correct, phase II reversed, voltage lead 1 open
(l) Phase I correct, phase II reversed, voltage lead 2 open
(m) Phase I correct, phase II reversed, voltage lead 3 open
(n) Phase I and phase II reversed, voltage lead 1 op en
(o) Phase I and phase II reversed voltage lead 2 open
(p) Phase I and phase II reversed, voltage lead 3 open

The presence or absence of current transformers does not in any way affect the number of arrangements of connections. However, this is not true of voltage transformers; and where their presence introduces additional arrangements of connections, their action was studied.

Class A Meters

The correct connections of the Class A type of polyphase meter when used without voltage transformers is shown in Fig. 1.

Phases I and II of the three-phase line contain the current transformers which supply current to the current coils I and II of the meter, respectively.

(In all of the figures used in this paper, the current coils are placed horizontally and numbered with the Roman numerals I and II. The voltage coils are placed at right angles to the current coils, and their terminals are numbered according to the three-phase line to which they are connected.)

The number of possible arrangements of the voltage connections to the four meter terminals are in this case given by the expression

$$y = \frac{\underline{|x}}{\underline{|2}}$$

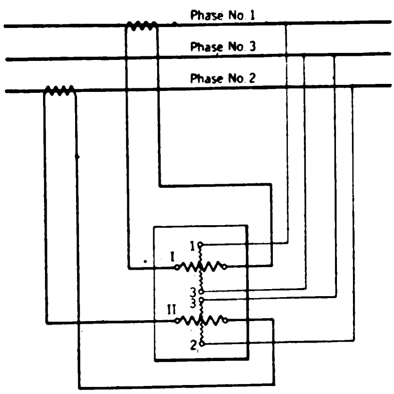

FIG. 1

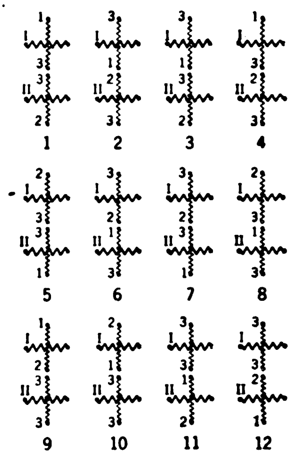

FIG. 2

as two of the voltage terminals are connected to the same phase. Substituting the value of x we find that there are 12 possible arrangements of the connections. These are shown diagrammatically in Fig. 2.

There are also 24 additional arrangements of the voltage connections possible. Twelve of these are formed by connecting two of the meter terminals to phase 1, one terminal to phase 2, and one to phase 3; the other twelve are formed by connecting two meter terminals to phase 2, and to phase 1, and one to phase 3. All of these arrangements are incorrect. They are treated in Tables VIII and IX.

The first eight of these arrangements, Fig. 2, illustrate not only the correct connections, but also mistakes that are more or less commonly made. Wrong connections as illustrated by the last four arrangements of connections are practically impossible except in meters where the terminals belonging to each element are not readily identified. Such connections are just as improbable as the connections of the leads of a current transformer to the terminals of the different current coils. They have been included in this investigation only for the sake of completeness, and to prove that mistakes of this character may be eliminated by the method that will be outlined for the checking of connections.

As each arrangement of voltage connections has 16 possible arrangements or combinations of the connections of the current coils, and opening the voltage leads, we have a total of 192 theoretically different possible connections for this class of meter when used without voltage transformers.

Calculation of the Theoretical Expressions

In order to study the effect of any one of the 192 connections upon the operation of the meter it was necessary to derive the theoretical expression for each case, from which the rate of rotation of the disk could be calculated for any load. The following examples serve to illustrate the method followed and the meaning of the expressions found.

Let P = the reading of the polyphase wattmeter.

E = the line voltage

E_1, E_2, E_3, I_1, I_2 and I_3, represent the phase voltages and currents respectively.

Φ_1, Φ_2 and Φ_3 represent the phase angles respectively. For the purpose of calculations we shall assume a balanced load with lagging power factor, and that the system is star-connected. Then we have

$$E_1 = E_2, = E_3,$$
$$E_{1,3} = E_{2,3} = E_{1,2} = E$$
$$I_1 = I_2, = I_3, = I$$
$$\text{and } \Phi_1 = \Phi_2, = \Phi_3, = \Phi$$

The power of the circuit is given by the expression $(+\sqrt{3}\cos\Phi)\,I\,E$.

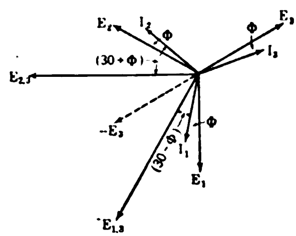

Fig. 3

Calculation of the Value of P for the Case 1 (*a*);
Phase I and II Correct.

The meter is connected as in Fig. 1 and the vector diagram of the circuit is shown in Fig. 3.

Now,

$$P = I_1 E_{1,3} \cos (3\,0 - \Phi) + I_2 E_{2,3} \cos (30 + \Phi)$$

$$= I\,E \left(\frac{\sqrt{3}}{2} \cos \Phi + \frac{1}{2} \sin \Phi \right)$$

$$+ I\,E \left(\frac{\sqrt{3}}{2} \cos \Phi - \frac{1}{2} \sin \Phi \right)$$

We find that $P = (+\ \sqrt{3} \cos \Phi)\ I\ E$

The value of P equals the actual power of the circuit and therefore the connections, case 1 (a), are correct and the meter registers correctly the power consumed. It must be kept in mind that the use of the term correct applies to the connections only and not to the calibration of the instrument.

Case 1 (b) *Phase I Reversed, Phase II Correct.*

We have now for P the expression

$$P = -\ I_1 E_{1,3} \cos (30 - \Phi) + I_2 E_{2,3} \cos (30 + \Phi)$$

$$P = (-\ \sin \Phi)\ I\ E$$

The meter does not register correctly and will run in the wrong direction with lagging currents. At unity power factor it will not run. The connections are therefore incorrect.

Case 1 (c) *Phase I Correct, Phase II Reversed.*

We find that $P = (+\ \sin \Phi)\ I\ E$

The meter will run in the right direction but not at the correct speed. The connections are therefore incorrect. At unity power factor the meter will not register.

Case 1 (d) *Phase I and Phase II Reversed.*

We find $P = (-\ \sqrt{3} \cos \Phi)\ I\ E$

The meter runs in the wrong direction and therefore the connections are at fault.

Case 1 (e) *Phase I and Phase II Correct, Voltage Lead* 1 *Open.* For this we get

$$P = \left(+ \frac{\sqrt{3}}{2} \cos \Phi - \frac{1}{2} \sin \Phi \right) I\ E$$

The direction of rotation will change from right to wrong when the power factor changes from values above 0.5 to values below 0.5. The connections are incorrect.

Case 1 (f) *Phase I and Phase II Correct, Voltage Lead* 2 *Open.* P becomes

$$P = \left(+\frac{\sqrt{3}}{2}\cos\Phi + \frac{1}{2}\sin\Phi\right) I\,E$$

The meter runs in the right direction, but does not register correctly.

Case 1 (g) *Phase I and Phase II Correct, Voltage Lead* 3 *Open.* For this case the value of P is indefinite. It may have the same value as 1 (e) or 1 (f) depending upon which of the leads 3 is open; or it may equal zero if both of them are open simultaneously. Therefore this case does not exist as a special case for this type of meter.

The above examples of the derivation of the theoretical expressions for P, with the addition of cases 2 (d), 6 (a) and 9 (a), will serve fully to illustrate the method of derivation.

Case 2 (d) *Phase I and Phase II Reversed.*

We find that

$$P = -\,I_1\,E_{3,1}\cos\{\pi - (30 - \Phi\} - I_2\,E_{3,2}\cos\{\pi - 30 \;+\Phi)\}$$

$$P = (+\,\sqrt{3}\cos\Phi)\,I\,E$$

The meter will run in the right direction and register correctly the power, therefore the connections of case 2 (d) are correct.

Case 6 (a) *Phase I and Phase II correct.*

The vector diagram for this arrangement of connections is given in Fig. 4.

$$P = I_1\,E_{3,2}\cos(90 + \Phi) + I_2\,E_{3,1}\cos(90 - \Phi)$$
$$P = 0$$

The meter will not rotate and the connections are incorrect.

Case 9 (a) *Phase I and Phase II Correct.*

$$P = I_1\,E_{1,2}\cos(30 + \Phi) + 0$$

$$P = \left(+\,\frac{\sqrt{3}}{2}\cos\Phi - \frac{1}{2}\sin\Phi\right) I\,E$$

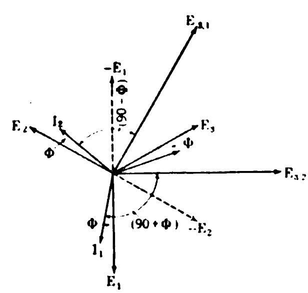

FIG. 4

The theoretical value of P for each one of the cases is given in Table II. The expressions are given in brackets and in every case the common term $I\,E$ has been omitted from the table.

the sine terms by (— 1). The table also gives the direction of rotation of the disk for four different values of lagging power factor with each arrangement of connections. By the use of the table it is also possible in cases where incorrect or open connections are found, to determine from the meter readings, when the conditions of the circuit are known, the actual kilowatt-hours that have been used.

Checking the Connections

From Table II we see that there are 64 cases or arrangements of connections where the meter will run in the right direction at some value of the power factor between unity and zero lagging. Forty of these 64 occur on open circuits and 24 when all circuits are intact. As all meters and instrument transformers are tested for open circuits before they are installed, these 24 cases are the important ones. We must therefore consider the problem of ascertaining some simple means for the identification of the correct connections among the 24 arrangements. We also learn from the table that there are four arrangements of connections which give correctly the power passing through the meter. These four correct arrangements of connections are 1 (a), 2 (d), 3 (b) and 4 (c).

One of the most common methods in use for checking the correctness of the connections has been to open the current or voltage supply of first one element and then the other, noting the direction of rotation in each case. For power factors above 0.5 this should give rotation in the right direction for either element, and for below that value, in the right direction for one element and in the wrong direction for the other. A study of Table II shows that this is true for the four correct cases 1 (a), 2 (d), 3 (b) and 4 (c), and that at unity power factor it serves to eliminate all incorrect connections. Further study, however, shows that for power factors above 0.5 and below unity there are four other cases, 5 (c), 6 (b), 7 (d) and 8 (a), which also give continued rotation in the right direction when the voltage supply to either element is opened. We also find that the test may be relied upon for power factor below 0.5. A knowledge of the power factor is essential for its application.

New Method of Checking Connections

The method that the writer proposes for the checking of the correctness of the connections, is the interchange of voltage leads

TABLE II

	(b) Phase I reversed, " II correct, Voltage lead I open.	(c) Phase I correct, " II reversed, Voltage lead II open.	
	$(+\frac{1}{2}\sqrt{3}\cos\Phi - \frac{1}{2}\sin\Phi)$ Right " Stop Wrong	$(-\sin\Phi)$ Stop Right " "	
	$(-\frac{1}{2}\sqrt{3}\cos\Phi + \frac{1}{2}\sin\Phi)$ Wrong " Stop Right	$(-\sin\Phi)$ Stop Wrong " "	
	$(+\frac{1}{2}\sqrt{3}\cos\Phi - \frac{1}{2}\sin\Phi)$ Right " Stop Wrong	$(-\sqrt{3}\cos\Phi)$ Wrong " " "	
	$(-\frac{1}{2}\sqrt{3}\cos\Phi + \frac{1}{2}\sin\Phi)$ Wrong " Stop Right	$(+\sqrt{3}\cos\Phi)$ Right " " "	
	$(-\sin\Phi)$ Stop Wrong " "	$(+2\sin\Phi)$ Stop Right " "	
	$(+\sin\Phi)$ Stop Right " "	$(-2\sin\Phi)$ Stop Wrong " "	
	$(+\sin\Phi)$ Stop Right " "	(0) Stop " "	
	$(-\sin\Phi)$ Stop Wrong " "	(0) Stop " "	
	(0) Stop " "	$(+\frac{1}{2}\sqrt{3}\cos\Phi - \frac{1}{2}\sin\Phi)$ Right " Stop Wrong	
	(0) Stop " "	$(-\frac{1}{2}\sqrt{3}\cos\Phi + \frac{1}{2}\sin\Phi)$ Wrong " Stop Right	
	(0) Stop " "	$(-\frac{1}{2}\sqrt{3}\cos\Phi - \frac{1}{2}\sin\Phi)$ Wrong " " "	
	(0) Stop " "	$(+\frac{1}{2}\sqrt{3}\cos\Phi + \frac{1}{2}\sin\Phi)$ Right " " "	

1 and 2. Then if the original connections were correct, the rotation of the meter disk will cease at any value of the power factor (leading or lagging) on a balanced circuit. If the original connections were not correct, rotation in one direction or the other will take place after the interchange has been made. The proof of this is as follows:

Unity Power Factor. At unity power factor we find that for 12 cases the meter will run in the right direction with all the circuits intact. These are as follows: 1 (a), 2 (d), 3 (b), 4 (c), 9 (a), 9 (c), 10 (b), 10 (d), 11 (a), 11 (b), 12 (c) and 12 (d).

The effect of the interchange of voltage leads 1 and 2 is given in Table III. Table III and also Tables IV, V, VI and VII are derived from the values given in Table II. We note in Table III, that when the voltage leads 1 and 2 are interchanged, the rotation of the disk will cease for the four correct connections, and that in all of the other cases it will run in the wrong direction.

Power Factor < 1.0 *and* > 0.5 *lagging.* Under these conditions we find 20 cases where the meter will run in the right direction with all circuits intact. These are: 1 (a), 2 (d), 3 (b), 4 (c), 1 (c), 2 (b), 3 (d), 4 (a), 5 (c), 6 (b), 7 (d), 8 (a), 9 (a), 9 (c), 10 (b), 10 (d), 11 (a), 11 (b), 12 (c) and 12 (d).

The effect of the interchange of voltage connections on these cases is given in Table IV. From the table we see that, when the voltage connections are interchanged, the meter will stop for the four correct cases only, and for all other connections the meter will run either forward or backward.

Power Factor $= 0.5$ *Lagging.* At this power factor we find from Table II that there are 16 cases where the meter will run in the right direction. These are: 1 (a), 2 (d), 3 (b), 4 (c), 1 (c), 2 (b), 3 (d), 4 (a), 5 (c), 6 (b), 7 (d), 8 (a), 11(a), 11 (b), 12 (c) and 12 (d).

The effect that is produced by an interchange of the voltage leads 1 and 2 is given in Table V. We find after interchanging the leads that for each of the four correct connections the meter will stop, and that for any one of the other 12 cases the meter disk will rotate either right or wrong.

Power Factor < 0.5 *Lagging.* For a power factor of less than 0.5 we see from Table II that there are 20 cases where the meter disk will run in the correct direction, with all connections intact. These are as follows: 1 (a), 2 (d), 3 (b), 4 (c), 1 (c), 2 (b), 3 (d), 4 (a), 5 (c), 6 (b), 7 (d), 8 (a), 9 (b), 9 (d), 10 (a), 10 (c), 11 (a), 11 (b), 12 (c) and 12 (d).

TABLE III—POWER FACTOR = 1.0

Case	Voltage leads 1 and 2 interchanged gives case	Directon of Rotation of meter then becomes
1 (a)	5 (a)	Stop
2 (d)	6 (d)	"
3 (b)	7 (b)	"
4 (c)	8 (c)	"
9 (a)	10 (a)	Wrong
9 (c)	10 (c)	"
10 (b)	9 (b)	"
10 (d)	9 (d)	"
11 (a)	12 (a)	"
11 (b)	12 (b)	"
12 (c)	11 (c)	"
12 (d)	11 (d)	"

TABLE IV—POWER FACTOR < 1 AND > 0.5 LAGGING.

Case	Voltage leads 1 and 2 interchanged gives case	Direction of rotation of meter then becomes	Case	Voltage leads 1 and 2 interchanged gives case	Direction of rotation of meter then becomes
1 (a)	5 (a)	Stop	7 (d)	3 (d)	Right
2 (d)	6 (d)	"	8 (a)	4 (a)	"
3 (b)	7 (b)	"	9 (a)	10 (a)	Wrong
4 (c)	8 (c)	"	9 (c)	10 (c)	"
1 (c)	5 (c)	Right	10 (b)	9 (b)	"
2 (b)	6 (b)	"	10 (d)	9 (d)	"
3 (d)	7 (d)	"	11 (a)	12 (a)	"
4 (a)	8 (a)	"	11 (b)	12 (b)	"
5 (c)	1 (c)	"	12 (c)	11 (c)	"
6 (b)	2 (b)	"	12 (d)	11 (d)	"

TABLE V.
POWER FACTOR = 0.5 LAGGING.

Case	Voltage leads 1 and 2 interchanged gives case	Direction of rotation of meter then becomes
1 (a)	5 (a)	Stop
2 (d)	6 (d)	"
3 (b)	7 (b)	"
4 (c)	8 (c)	"
1 (c)	5 (c)	Right
2 (b)	6 (b)	"
3 (d)	7 (d)	"
4 (a)	8 (a)	"
5 (c)	1 (c)	"
6 (b)	2 (b)	"
7 (d)	3 (d)	"
8 (a)	4 (a)	"
11 (a)	12 (a)	Wrong
11 (b)	12 (b)	"
12 (c)	11 (c)	"
12 (d)	11 (d)	"

These cases are treated in Table VI, and it is evident that the rotation of the disk, as before, only ceases when the original connections were correct before the leads 1 and 2 were interchanged, and that for all other arrangements, rotation either forward or backward will take place.

Power Factor <1.0 *and* >0.5 *Leading.* We find from Table II

TABLE VI
POWER FACTOR < 0.5 LAGGING.

Case	Voltage leads 1 and 2 interchanged gives case	Direction of rotation of meter then becomes	Case	Voltage leads 1 and 2 interchanged gives case	Direction of rotation of meter then becomes
1 (a)	5 (a)	Stop	7 (d)	3 (d)	Right
2 (d)	6 (d)	"	8 (a)	4 (a)	"
3 (b)	7 (b)	"	9 (b)	10 (b)	Wrong
4 (c)	8 (c)	"	9 (d)	10 (d)	"
1 (c)	5 (c)	Right	10 (a)	9 (a)	"
2 (b)	6 (b)	"	10 (c)	9 (c)	"
3 (d)	7 (d)	"	11 (a)	12 (a)	"
4 (a)	8 (a)	"	11 (b)	12 (b)	"
5 (c)	1 (c)	"	12 (c)	11 (c)	"
6 (b)	2 (b)	"	12 (d)	11 (d)	"

TABLE VII
POWER FACTOR < 1.0 AND > 0.5 LEADING.

Case	Voltage leads 1 and 2 interchanged gives case	Direction of rotation of meter then becomes	Case	Voltage leads 1 and 2 interchanged gives case	Direction of rotation of meter then becomes
1 (a)	5 (a)	Stop	7 (a)	3 (a)	Right
2 (d)	6 (d)	"	8 (d)	4 (d)	"
3 (b)	7 (b)	"	9 (a)	10 (a)	Wrong
4 (c)	8 (c)	"	9 (c)	10 (c)	"
1 (b)	5 (b)	Right	10 (b)	9 (b)	"
2 (c)	6 (c)	"	10 (d)	9 (d)	"
3 (a)	7 (a)	"	11 (a)	12 (a)	"
4 (d)	8 (d)	"	11 (b)	12 (b)	"
5 (b)	1 (b)	"	12 (c)	11 (c)	"
6 (c)	2 (c)	"	12 (d)	11 (d)	"

that under these conditions there are 20 cases where the meter will run in the right direction, with all circuits intact. These are: 1 (a), 2 (d), 3 (b), 4 (c), 1 (b), 2 (c), 3 (a), 4 (d), 5 (b), 6 (c), 7 (a), 8 (d), 9 (a), 9 (c), 10 (b), 10 (d), 11 (a), 11 (b), 12 (c), and 12 (d).

The effect of interchanging leads 1 and 2 on these cases is treated in Table VII. It is clear from Table VII that the rota-

tion of the disk, as for lagging values of the power factor, only ceases for the four correct connections when the interchange is made, and that for all other arrangements rotation either forward or backward will take place.

It may further be proved from Table II that for other values of leading power factor, an interchange of the voltage connections 1 and 2 will cause the rotation of the disk to cease for the four correct connections only.

It is evident from the above proof, that with a balanced load (motor load), the correctness of the connections of a polyphase watt-hour meter, provided with four voltage terminals, can be accurately checked at any power factor by the simple interchange of the voltage connections to the phases 1 and 2, when the meter is used without voltage transformers, and if the meter stops the original connections were correct.

The interchange may be easily and simply made at the meter terminals. The following set of rules for the identification of connections may be deduced from Tables II, III, IV, V, VI and VII.

1. If, after the interchange of voltage connections 1 and 2, the meter stops, then the original connections were correct.

2. If, after the interchange of voltage connections 1 and 2, the meter continues to run in the right direction at increased speed, then the original connection was either 1 (c) or 2 (b) or 3 (d) or 4 (a), for leading currents 1 (b), 2 (c), 3 (a) or 4 (d), and the reversal of the connections of one of the current coils is all that is needed to rectify the mistake.

3. If, after the interchange the meter continues to run " right " but at greatly reduced speed (one-half its former speed) then the original was one of the arrangements of 5, 6, 7 or 8 and the voltage connections are now correct. The reversal of the proper current coil is all that is needed to make the connections correct.

4. If, after the interchange the meter runs in the wrong direction, then the original connection belonged to arrangements 9, 10, 11 or 12 and the entire system of connections must be carefully gone over and corrected.

The theoretical expressions for P for each of the 24 additional arrangements, mentioned above, are given in Tables VIII and IX. As stated, twelve of these arrangements are formed by connecting two meter terminals to phase 1, one to phase 2, and one to phase 3; and twelve by connecting two terminals to phase 2, one to phase 1, and one to phase 3. In Tables VIII and IX the

unimportant arrangements similar to arrangements 9, 10, 11 and 12 of Fig. 2 have been omitted. The expressions for these unimportant arrangements may be found elsewhere if needed. For example, consider arrangement 9 of Table VIII. Arrangement 9, Table VIII, is made by connecting the voltage terminals of meter element I to phases 2 and 3, and by connecting both voltage terminals of meter element II to phase 1. The theoretical expressions for the resulting cases are to be found in Table II, arrangement 5, cases (e), (h), (k) and (n).

Checking the Connections

The elimination of the incorrect connections treated in Tables VIII and IX is accomplished by the interchange of voltage leads 1 and 2. If the wiring is open the interchange is made at the meter terminals, and in places where the wires to the meter run in conduit the interchange is made at the line. In either case the inspection of the connections incidental to making the interchange indicates at once the mistake, as it is apparent that two of the voltage terminals are connected to one of the phases that supply the current coils of the meter with current. The correction of the mistake is simple.

Class A Meters with Voltage Transformers

The addition of voltage transformers complicates the connections, and makes possible a large number of additional connections. That this is a fact is clearly seen when one considers that the twelve arrangements of connections shown in Fig. 5 may be applied to the primary side of the transformers, and that for each one of these there are 24 different possible arrangements of the connections between the four secondary terminals of the transformers and the four voltage terminals of the polyphase meter.

Four of these arrangements are shown in Fig. 5. However, it is evident that the four arrangements shown in Fig. 5 are electrically the same. A careful study of the conditions shows that no new electrical arrangements of the circuits are introduced by a combination of any one of the first eight cases applied to the primary side of the transformers with any one of the first eight arrangements between the secondaries of the transformers and the meter. The same is also true when any one of the last four cases on the primary side is combined with any one of the same cases on the secondary side. However, any combination

made with any one of the first eight arrangements on the primary side, with any one of the last four on the secondary side of the transformers, introduces new cases. In all of these new cases which are brought about by the addition of the voltage transformers, the two secondary windings of the transformers and the two voltage coils of the polyphase meters are in series. Two of these cases are illustrated in Fig. 6.

For any one of these added cases formulas for the rate and direction of rotation can be derived if necessary. These cases are not only very improbable, but a reversal of the voltage leads 1 and 2 on the primary sides of the transformers will in no case cause the meter to stop. Therefore, the use of voltage transformers does not introduce any new cases of importance, and the expressions given in Tables II, VIII and IX apply to this type of meter when used with transformers.

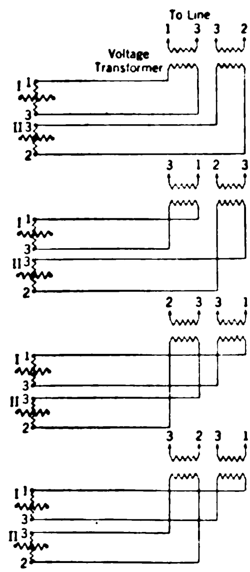

Fig. 5

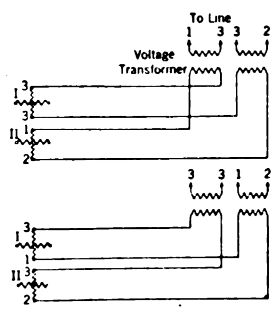

Fig. 6

Since the same expressions for P hold good, irrespective of the presence or absence of voltage transformers, the same mode of checking the connections is applicable in both cases. Therefore, the correct connections of a polyphase watt-hour meter, provided with four separate voltage terminals, when used with voltage transformers, may be checked by the interchange of voltage connections 1 and 2 on the primary side of the voltage transformers. And if the connections were originally correct, and the load is balanced, the meter will stop at any power factor. Further, if we assume that all of the improbable connections of cases 9, 10, 11 and 12 of Table II are absent, and that all incor-

rect connections illustrated in Tables VIII and IX will be eliminated by the inspection of the connections incidental to making the interchange, then we may apply rules 1, 2 and 3 for the correction of mistakes in the connections.

CLASS B METERS

The correct connections of Class B type of polyphase meter are shown in Fig. 7. With this class of meter the presence of voltage transformers does not introduce any new cases, and therefore the following discussion applies equally well to meters of this type when used either with or without voltage transformers.

The number of possible arrangements of the voltage connections to the three meter terminals is found to be six. These are

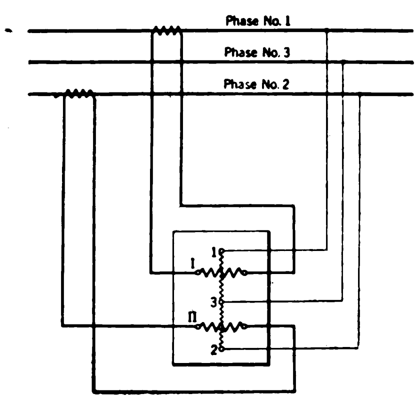

FIG. 7

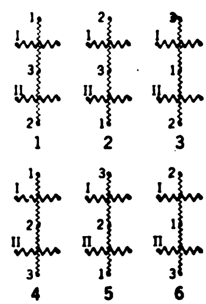

FIG. 8

shown in Fig. 8. As in the case of Class A meters, each arrangement of the voltage connections has four different arrangements of the current coils, and each arrangement of the connections of the current coils has four conditions of operation, depending upon whether all the voltage connections are intact or if one of them is open. Therefore, we find a total of 96 different connections or cases.

The theoretical expressions for P were derived for each one of the cases, and these are to be found in Table X. With this type of meter, the opening of the voltage connection 3 does not give a case analogous to those due to the opening of either leads 1 or 2, but a separate and distinct case. The following example will serve to illustrate the derivation of the value of P for these cases:

Case 1 (g) *Phase I and Phase II Correct, Voltage Lead* 3 *Open.* The vector diagram is given in Fig. 9. The voltage is divided between the two potential coils of the meter, and therefore, half of the voltage is across each coil and we find that

$$P = \frac{1}{2} I_1 E_{1,2} \cos (30 + \Phi) + \frac{1}{2} I_2 E_{2,1} \cos (30 - \Phi)$$

$$P = \left(+ \frac{\sqrt{3}}{2} \cos \Phi \right) I E$$

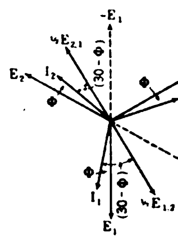

FIG. 9

The correctness of each of the 96 expressions was checked experimentally as in the case of the Class A type of meter. Table X not only gives the expressions but also the directions of rotation of the meter disk at several different values of lagging power factor.

CHECKING OF CONNECTIONS

From Table X we find that there are 60 cases where the meter will run in the correct direction at some power factor between unity and zero lagging, however, only 12 of these are for cases where all the circuits are intact. These 12 are as follows: 1 (a), 1 (c), 2 (c), 3 (b), 4 (b), 4 (c), 5 (b), 5 (c), 5 (d), 6 (a), 6 (b) and 6 (d).

Of these 12 cases there is only one case where the meter registers correctly under all conditions the amount of power consumed, and that is case 1 (a). A careful study of the table does not reveal any simple method of checking the correctness of the connections 1 (a) that does not apply equally well to some of the incorrect cases. The arrangements of connections that do not offer any simple means of elimination are cases 5 (d), 6 (a) and 6 (d). However, mistakes that are illustrated by cases coming under 3, 4, 5 and 6 are not often made, especially if the common voltage terminal of the meter to which phase 3 is connected is plainly marked. If this terminal is marked, it is practically impossible to make any mistake in its connection to the proper phase, and therefore, we need only consider cases coming under arrangements 1 and 2.

Under arrangements 1 and 2 of the voltage connections we find only three cases where the meter will run in the right direction. These are: 1 (a), 1 (c) and 2 (c). In addition to the check of the

Phase I " II Voltage	(e) Phase I correct " II [illegible] Voltage lead	(f) Phase I reversed " II " Voltage leads current	(g) Phase I correct " II [illegible] Voltage lags current
$(-3\sqrt{3}$ [illegible]	[illegible] Φ [illegible] Right " Stop Wrong	$(\Phi$ cos [illegible] $)$ Wrong " "	[illegible] $\Phi)$ [illegible] Right " "
[illegible]	[illegible] Φ [illegible] Stop Right " "	0 Stop " "	Φ [illegible] Right " "
[illegible] $3\sqrt{3}$ [illegible]	[illegible] Φ [illegible] Right Wrong "	0 Stop "	[illegible] Φ [illegible] Wrong " " "
[illegible] $+ 3\sqrt{3}$ [illegible]	[illegible] Φ [illegible] Wrong " Stop Right	0 Stop " "	[illegible] Φ [illegible] Right " Stop Wrong
$(-$ [illegible]	$(\Phi$ [illegible] $)$ Stop Wrong " "	[illegible] Φ [illegible] Right " " "	[illegible] Φ [illegible] Right " Stop Wrong
[illegible] $+ 3\sqrt{3}$ [illegible]	[illegible] Φ [illegible] Wrong Right "	[illegible] Φ [illegible] Right Wrong	[illegible] Φ [illegible] Wrong " " "

Phase I " II Voltage	(h) Phase I correct " II " Voltage leads	Power Factor	Arrangement
$(-$ [illegible]	[illegible] $\sqrt{3}$ [illegible] Right " " "	1.0 $> 1.8 > .5$ .5 $< .5$	1
	[illegible] $\sqrt{3}\cos\Phi$ Right " " "	1.0 > 1 [illegible] $> .5$ .5 $< .5$	2
	[illegible] Φ Right " Stop Wrong	1.0 $> 1 \& > .5$ .5 $< .5$	3

correctness of the connections produced by the opening of the voltage supply to each element of the meter in turn, there is also a check that is sometimes employed with this class of meter which consists in opening lead 3.

The same criticism, namely, that it cannot be relied upon, that applied to the check obtained by opening the voltage supply of each element in turn, as applied to the Class A type of meter, applies equally well when used with this class of meters. When we study the effect of opening lead 3, we see from Table VIII that when we open lead 3 for case 1 (a) we get case 1 (g), and the meter continues to run in the right direction at exactly one-half speed. For case 1 (c) we get 1 (m) and the meter now runs in the wrong direction, and for case 2 (c) we get 2 (m), and the meter continues to run in the right direction at exactly one-half its former speed. Therefore, this check fails to differentiate between 1 (a) and 2 (c).

Check Produced by the Interchange of the Voltage Connections to Phases 1 and 2

At unity power factor we have only case 1 (a) possible and an interchanging of the voltage leads 1 and 2 will give case 2 (a) and the rotation of the disk will cease. This is also true of case 1 (a) for any value of the power factor either leading or lagging.

At all values of lagging power factor below unity, we may have in addition to case 1 (a) either 1 (c) or 2 (c). The interchange for voltage leads for the case 1 (c) gives case 2 (c) and the meter continues to run in the right direction at double its original speed. The interchange for case 2 (c) gives 1 (c) and the meter continues to run in the right direction at one-half its original speed.

For leading values of the power factor we find three cases where the meter disk will rotate in the right direction. These are: 1 (a), 1 (b) and 2 (b). In cases 1 (b) and 2 (b) the disk will continue to rotate in the right direction after the interchange is made.

It is evident from the above, that the interchange of the voltage leads 1 and 2 will serve to eliminate all incorrect connections and check the proper connections for Class B meters, if we allow the assumption that the common voltage terminal is connected to its proper phase, *i. e.*, to the phase that does not supply current to the current coils of the meter. This connection is very simple if the terminal is clearly marked. Rules 1 and 2 also

apply to this meter, and aid in the correction of mistakes. The interchange of leads 1, 2 and 3 may always be made at the terminals of the instrument.

Class C Meters

The correct connections of the Class C type of meter are shown in Fig. 10. Instrument transformers are not used with this type of meter, which is essentially a house meter. The three possible arrangements of the voltage connections are illustrated in Fig. 11.

The expressions for P and the direction of rotation at different power factors are given in Table XI.

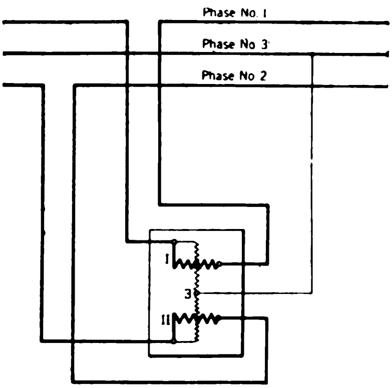

Fig. 10

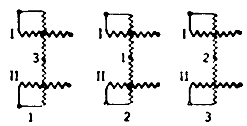

Fig. 11

Checking the Connections

Table XI shows that there are 8 cases where the meter will run in the right direction at some value of the power factor, when all its circuits are intact. Of these 8 cases, case 1 (a) is the only case or arrangement of connections where the meter will operate correctly under all conditions. The 8 cases are: 1 (a), 1 (c), 2 (a), 2 (b), 3 (a), 3 (b), 3 (c) and 3 (d).

The check for this class of meters consists in opening the single voltage connections to the meter*; for case 1 (a) this gives 1 (g) and the meter continues to run in the right direction at one-half its former speed.

The opening of the voltage connection for case 1 (c) gives case 1 (m) and the meter stops or runs in the wrong direction, depending on the power factor. The opening of the voltage connections for any one of the remaining cases causes the meter to stop under all conditions. It may be stated that a balanced load is not essential for making the test.

* *Electrical World*, Vol. 63, p. 144, 1914.

Opening the Supply as a Method of Checking the Connections

In addition to the above-mentioned checks there is a test of the correctness of the connections that may be applied where it is permissible to open one phase at a time of the supply without interrupting the load. The circuit must be opened between the meter and the supply line.

This test is as follows: Assume that the meter is connected in a three-phase circuit, where one of the phases may be opened without interrupting the load, and that the fuses are between the meter and the supply line. Now, with the meter running in the right direction, open one of the phases that supplies current to one of the current coils of the meter. The meter should continue to rotate in the right direction if the connections are correct; because it is now operating as a single-phase meter, registering the power supplied to a single-phase load. Replace the fuse and open the phase that supplies current to the other current coil of the meter. The meter should continue to rotate in the right direction for the same reason as before. If the meter stops or if its direction of rotation changes when either line is open, then the connections are incorrect and must be carefully traced out and the mistake rectified. In making this test it is not necessary to know the power factor of the load nor is a balanced load necessary.

The circuit must be opened between the meter and the supply line, because if the opening is made between the meter and the load, both voltage coils of the meter will still be excited and we may have such incorrect connections as cases 5 (c), 5 (b), 7 (d), 8 (a) of Table II or 2 (c) of Table X which also will give rotation in the right direction with either line open. The test will then fail to eliminate the incorrect connections.

Example of the Application of the New Method

The following is an example of the application of the method of checking the correctness of a polyphase watt-hour meter on a three-phase circuit by means of the interchange of voltage connections to phases 1 and 2. For this example the writer has assumed that we have to install a polyphase watt-hour meter with four voltage and four current terminals on a circuit requiring the use of voltage and current transformers. While making the test the load on the circuit must be balanced and may consist of a three-phase induction motor, a three-phase bank of trans-

formers or other similar apparatus. As it is difficult to obtain a balanced load with lamps, the lighting circuits should be open.

Connect the meter according to the diagram of connections (see Fig. 12) so that it rotates in the right direction.

Having obtained rotation in the right direction, interchange the connections on the primary side of the potential transformers to phases 1 and 2, and if rotation ceases the original connections were correct, and should be restored.

If after making the interchange, the meter continues to run in the right direction but at increased speed, the original connections were correct, but the connections of one of the current coils were reversed. Restore the voltage connections to their

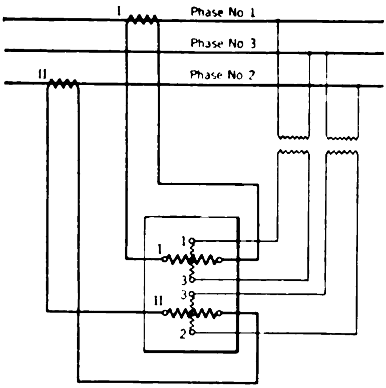

Fig. 12

original condition and reverse the connections of the current coil that will give rotation in the right direction after reversal.

If, after making the interchange, the meter continues to run in the right direction, but at reduced speed, the voltage connections are now correct, and one current coil is reversed. Reverse the connections of the current coil that will give rotation in the right direction after reversal.

Having satisfied the conditions of the test, the voltage terminals of the meter that are at the same potential may be connected together and grounded if desired.

Summary and Conclusions

The results of the investigation show clearly, first: That the check upon the correctness of the connections made by opening the current or voltage supply to each element in turn, is unreliable

and may lead to erroneous results. Furthermore, a knowledge of the power factor is essential to its use.

Second: That the check upon the correctness of the connections made by opening the voltage connections to the phase that does not supply current to the two single-phase elements of the meter is only accurate in case of meters of Class C or to meters similarly connected.

Third: That the check upon the correctness of the connections made by opening in turn each of the three-phase lines that supply current to the current coils of the meter, is accurate at any power factor and on balanced or unbalanced load; provided the opening is made between the meter and the supply line.

Fourth: That the check upon the correctness of the connections made by the interchange of voltage connections to phases 1 and 2 is accurate at any power factor on a balanced load for Class B meters, if we make the assumption that phase 3 is connected to the proper terminal and that if the original connections were correct the meter stops. This also applies to meters having four voltage terminals when two of these are connected together, and from a common terminal.

Fifth: That the check upon the correctness of the connections made by the interchange of voltage leads 1 and 2 is accurate at any power factor on a balanced circuit for Class A meters, and that if the original connections were correct the meter stops.

Sixth: That in case the connections are incorrect for Class A and B meters, the interchange of leads 1 and 2 gives the necessary information for correcting the mistake (see Rules 2 and 3, page 172).

The investigation also shows that there is a simple means of ascertaining the power factor on a three-phase circuit where a polyphase watt-hour meter is installed. This method may be used with any type of meter. It is as follows: Note the time of one revolution of the disk when the meter is connected correctly and registering the given load. Then reverse the connections of either current coil, and note the time of one revolution, with the given load. Then

$$\tan \Phi = \frac{\sqrt{3}\ (\text{Time of one revolution, meter connected correctly})}{\text{Time of one revolution with one current coil reversed}}$$

The experimental work connected with this investigation was carried on in the new electrical laboratories of the Johns

Hopkins University. The writer wishes to thank Mr. J. R. Cruikshank, Dr. J. B. Whitehead, Mr. F. V. Magalhaes and Mr. W. S. Brown for their kindness and assistance.

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(*Subject to final revision for the Transactions.*)

THE TRUE NATURE OF SPEECH

With Application to a Voice-Operated Phonographic Alphabet Writing Machine

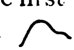
BY JOHN B. FLOWERS

Abstract of Paper

That speech is a rapid variation in intensity of the voice and mouth-tones according to definite sound patterns called letters of the alphabet, is proved, by showing that speech is the result of action of the mouth-parts in varying the intensity of the voice and mouth-tones, and through photographs taken with the string-galvanometer of each letter sound of the alphabet, showing definitely the characteristic variation in intensity of tone for each letter of the alphabet. From the curves, the phonographic alphabet is obtained by measuring the variations in intensity of the main tone of the record.

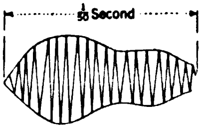
A design for a voice-operated phonographic alphabet writing machine is described. The object of this device is to record speech automatically in ink on paper in the form of an easily read compact system of natural characters called the phonographic alphabet. Its design comprises a high-power telephone transmitter controlling electric resonator circuits, the intensity of currents in which is measured by the vibration of mirrors reflecting light upon a selenium cell connected to a special recording pen.

Definition of Speech

SPEECH is a rapid variation in amplitude of one or more tones, there being a definite form of variation making a pattern for each letter sound of the alphabet. These patterns are not formed by the superposing of tones of different pitch to give a certain quality to the tone but by a definite form of variation in the amplitude of a single tone or tones. This previously unknown form of variation of amplitude, quite different from the ordinary change from soft to loud, should be called the speech-variation. What is meant is that if a tone of a pitch of say 1000 cycles per second commences in such a manner that the first 10 to 20 cycles vary in intensity after the definite pattern  , the sound *b* will be produced and heard.

Manuscript of this paper was received April 26, 1915.

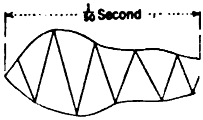
Thus:



20 CYCLES OF A 1000-CYCLE TONE

But no matter what the pitch of the tone, if its intensity is made to vary according to this definite pattern in a *small fraction of a second*, the sound *b* will be produced.

Thus:



5 CYCLES OF A 250-CYCLE TONE

When we speak the letter *b*, the fundamental tone and the overtones of the vocal chords together with the mouth-tones are all varied at the same instant of time according to the definite pattern . The same is true for each letter sound of the alphabet, as will appear in the table of patterns of the letters of the alphabet called the phonographic alphabet on another page:

In other words, if an open reed-organ pipe of, say, middle C pitch were blown and at its large open end were placed a mechanical device like the human mouth for opening, varying the opening, and closing the opening, and trilling and varying the air pressure, the organ pipe would speak like a human being, with wonderful power and majesty.

We quote Helmholtz: "Sensations of Tone," pages 66-67-68. "There has been a general inclination to credit quality with all possible peculiarities of musical tones that were not evidently due to force and pitch. But very slight consideration will suffice to show that many of these peculiarities of musical tones depend upon the way in which they begin and end. The methods of attacking and releasing tones are sometimes so characteristic that for the human voice they have been noted by a series of different letters. To these belong the explosive consonants *B*, *D*, *G*, and *P*, *T*, *K*. The effects of these letters are produced by opening the closed, or closing the open passage through the mouth. For *B* and *P* the closure is made by the lips, for *D* and *T* by the tongue and upper teeth, and *G* and *K*

by the back of the tongue and soft palate. In wind instruments where the tones are maintained by a stream of air, we generally hear more or less whizzing and hissing of the air which breaks against the sharp edges of the mouthpiece. It is well known that most consonants in human speech are characterized by the maintenance of similar noises, as F, V; S, Z; Th in thin and in then; the Scotch and German guttural CH, and Dutch G. For some the tone is made still more irregular by trilling parts of the mouth, as for R and L. In the case of R the stream of air is periodically entirely interrupted by trilling the uvula, or the tip of the tongue; and we thus obtain an intermitting sound to which these interruptions give a peculiar jarring character. In the case of L the soft side edges of the tongue are moved by the stream of air, and, without completely interrupting the tone, produce inequalities in its strength. The formation of M and N in so far resembles that of vowels, that no noise of wind is generated in any part of the cavity of the mouth, which is perfectly closed, and the sound of the voice escapes through the nose."

Proof that a Definite Fixed Pitch is Not the Chief Characteristic of Individual Letter Sounds

Anyone may easily prove this for himself. Place upon the phonograph a talking record. Run the record, first at 60 revolutions per minute, which is below the normal speed, then at 160 revolutions per minute, which is $2\frac{2}{3}$ times the lower speed. The articulation remains intelligible even at the low and high speeds. The pitches of all speech sounds at the high speed of the record are nearly an octave and a half above the pitches at the low speed. Hence if but one fixed pitch was characteristic of each letter sound, the speech would have been absolutely unintelligible. But the speech was entirely intelligible and therefore pitch is not the distinguishing element between letter sounds.

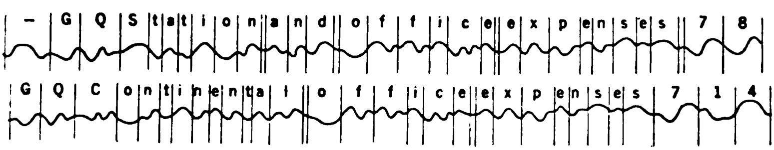
Definition of Vowels and Consonants

A vowel is a definite sound pattern which repeats itself at intervals, while a consonant is a definite sound pattern occurring but once. The consonant sound pattern must exist at least for 0.01 second, in order to be perceived by the brain, 0.01 second being the minimum perception time for speech sounds. The vowel sound patterns proper, are about 0.01 second in duration, but as they repeat themselves again and

again, may be of any duration the speaker desires. Under this definition, the consonants are b, c = k, d, g, j, k, p, t, and the vowels are, a, c = s, e, f, h, i, l, m, n, o, r, s, u, v, w = $\overline{\text{uo}}$, y, z.

Written language is made up of consecutive pattern pictures, one pattern or form standing for each letter of the alphabet, and the eye is able to distinguish between them if they approximate the standard form. Likewise, spoken language is made up of consecutive pattern pictures, one pattern or form standing for each letter of the alphabet, and I show in another paper not yet published, how the ear is able to distinguish between them when they approximate a standard form.

In reading a submarine cable message on the tape, the eye must pick out the pattern forms of each letter. That the eye can read these messages as fast as ordinary writing is known to all cable operators. Spoken language is similarly a succession of these different pattern forms, strung along one after the other, and the ear distinguishes each of these pattern forms as it arrives in the consecutive order of utterance, even as the eye distinguishes pattern forms of written or submarine cable language.



Cable Message Received by the W. U. Telegraph Co., February 11, 1915, Over an Atlantic Cable

Speech may be whispered using no voice (without movement of the vocal chords). This fact was determined by actual observation of quiet vocal chords during a whispered word, "ah."

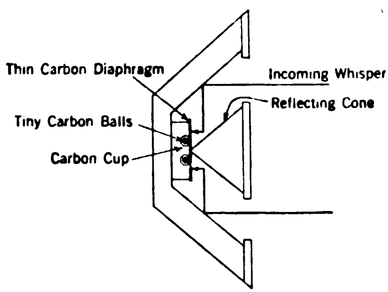
Distinction between Speech and Voice

Note the distinction between speech and voice and where each is produced, viz., voice by the vocal chords and speech through variation in the intensity of the compressed air forced through the throat, mouth, and nasal cavity. This variation in intensity is accomplished by the action of the muscles of the throat and mouth. Each person has a slightly different pitch of voice, men low and women high. An average man's voice has a pitch lying between 85 and 160 complete vibrations per

second, while the average woman's voice has a pitch lying between 150 and 320 complete vibrations per second. Thus, the pitch of one person's voice is different from another's.

But speech may be produced by whispering, that is, using no voice, and whispered speech always has the same sound, no matter who is the speaker, man or woman. Any person can determine this by his own observation, getting someone to whisper with him and comparing the sound of the whispers. No difference in the sound of the whispers can be heard. In other words, during a whisper, speech is independent of the vocal chord action.

All previous speech records have been taken of spoken or sung words and none of whispered words on account of the lack of instruments sufficiently sensitive to record whispered speech. The resulting spoken records contained the fundamental tones and overtones of the vocal chords as well as the mouth-tones and their variations combined in so complex a curve that no one has as yet succeeded in deciphering them.



SECTION OF ACOUSTICON TRANSMITTER FOR WHISPERED SPEECH

I found that the acousticon transmitter hooked up to the Einthoven string-galvanometer, as shown in the sketch herewith, were very satisfactory instruments for making records of whispered speech, as they are both marvelously sensitive instruments. On account of whispered speech being independent of vocal chord action, it was decided to make photographic records of it from which to determine by careful study the true nature of speech. It is evident that the whispered speech records will not show the voice-tones and overtones but will simply show the mouth-tones and their variations in intensity. It is easy to follow the variation in intensity of one or two tones on the whispered speech records and thus pick out the intensity pattern for each letter sound which I call the phonographic alphabet.

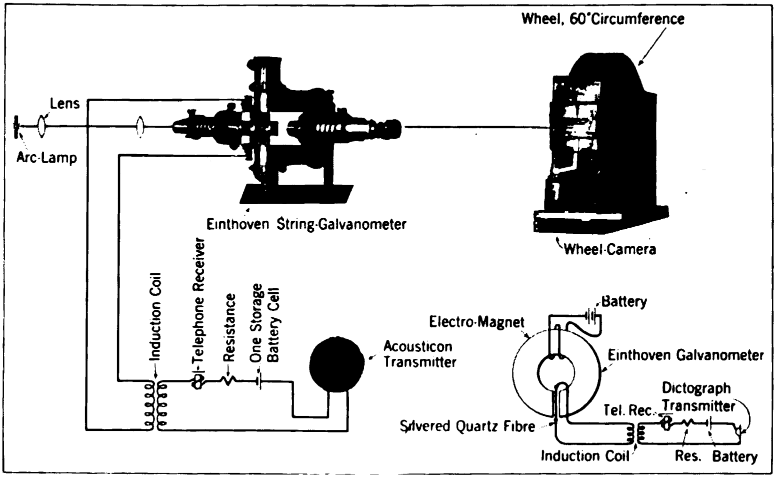
The diaphragm is made of very thin carbon and so covers the recesses in the carbon block, without touching it, as to prevent the tiny carbon balls from falling out. The sketch shows how the acousticon transmitter collects sound from a large area and by a reflecting system concentrates it on the middle of the carbon diaphragm. There is no spring pressing on the diaphragm and it is believed that the diaphragm moves like a piston with the rarefactions and compressions of the sound waves. It is a highly damped instrument due to the weight of the carbon balls pressing against the diaphragm resisting its motion.

Description of Method of Making Whispered Speech-Pattern Pictures

The acousticon transmitter was placed in a large sound-proof telephone booth and supported by suspension free of all vibration. The diagram shows how the speech current flows from the acousticon through the storage battery cell, through the resistance, through the telephone receiver, through the primary side of the induction coil, and back to the acousticon; on the secondary side of the induction coil, the speech current flows through the string of the galvanometer. The string galvanometer is an electrical instrument having a fine silver-plated quartz fiber, 0.0001 in. thick, supported between two poles of a huge electromagnet. Through a hole in the magnet poles, a powerful ray from an arc lamp is focused upon this quartz fiber or string. By means of another system of lenses, the image of the string is focused upon a slot in the rotating drum-camera. When a speech-current flows through this galvanometer string, the string vibrates back and forth in a direction at right angles to the lines of force of the magnet, and its lightest motion is magnified 900 times by the lens system. The shadow of the string vibrates back and forth on the camera-shutter almost exactly in proportion to the speech sounds. The camera photographs the vibrating shadow of the galvanometer string. A word is whispered repeatedly, and the speech is listened to in the telephone receiver as a check on the articulation of the words. When the shadow of the galvanometer string moves back and forth about two inches, a lever is pressed, the electrically operated camera-shutter is held open for one revolution of the wheel and a photographic record, five feet long, of the word whispered is obtained. Extra-rapid film was exposed and good photo-

graphs obtained at rates varying from 1000 feet to one mile per minute. The rate of 1080 ft. was used mostly in this work as it gave a record with good intervals between crests of speech-waves, the best record to analyze. By interrupting the light from the arc lamp, 500 times per second, vertical lines were photographed upon the film at intervals of 0.002 second by a specially constructed time-wheel, for the necessary time record.

For a consideration of the theory of the string galvanometer, I refer to Dr. A. C. Crehore on the "Theory of the String Galvanometer," *Phil. Mag.*, vol. 28, August, 1914. The amount of air and electromagnetic damping of the movement of the galvanometer string was large enough, so that the motion of

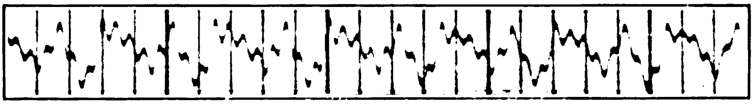


the string corresponded almost exactly to every component of the impressed speech currents, and the resulting speech records should be regarded as being as nearly correct records of speech as can be obtained by any recording instrument.

Speech patterns of the same letter sound are almost exactly identical for all persons and independent of age or sex of speaker. Five hundred records were obtained of three men's speech and one woman's speech which prove this.

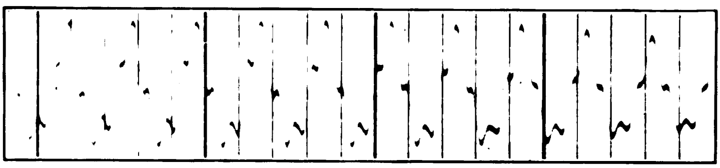
The Pattern Forms of the Natural Alphabet

Each of the letters has its own pattern form. All following records are of whispered speech, except Nos. 1 and 2.



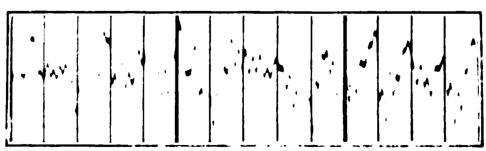
CURVE 1— ū in yū

Showing fundamental tone of voice to be 140 to 200 cycles per second. ū equals 1100 cycles per second superposed upon the lower note in definite pattern form. Male voice, spoken record.



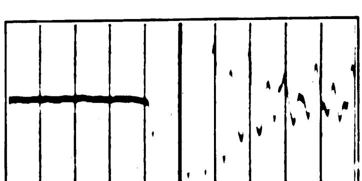
CURVE 2—ū in yū

Fundamental tone of voice shows 250 cycles per second. ū shows 1050 cycles superposed upon 250 cycles per second in definite pattern form. Female voice, spoken record.



CURVE 3—ā in āō

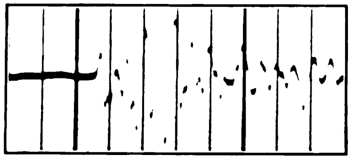
ā shows 2500 cycles per second superposed upon 500 cycles per second in definite pattern form. (Repeating pattern picture.)



CURVE 4—b in bāy

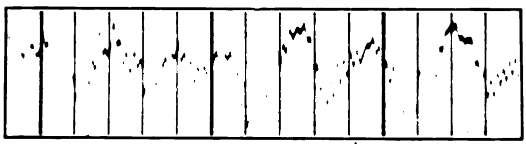
b shows special pattern picture.

c equals s.



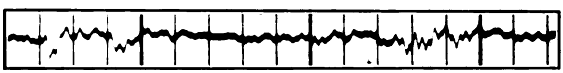
Curve 5—d in dāy

d shows special pattern picture.



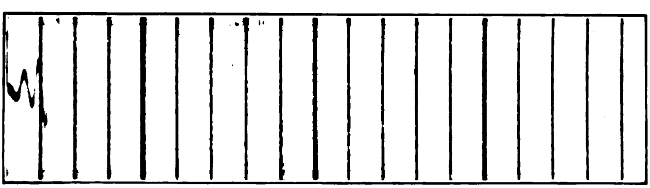
Curve 6—ē in mē

ē in me, shows 2500 cycles per second superposed on 200 cycles per second in special pattern picture. (Repeating pattern picture).



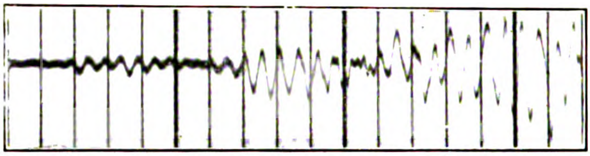
Curve 7—f in fēē

f in fēē, shows alternation of 1000 and 2500 cycles, special pattern. (Repeating).



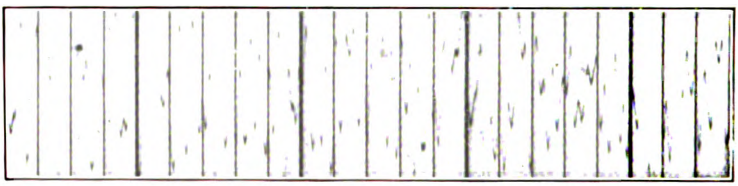
Curve 8—g in gō

g in go, shows special pattern picture.



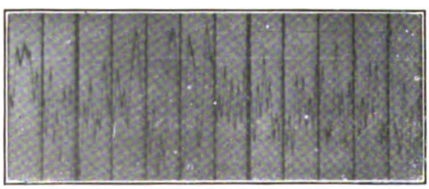
CURVE 9—h in hĭ

h in hi, shows special pattern picture. (Repeating).



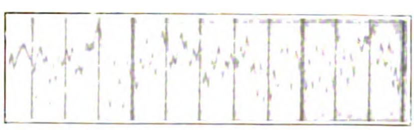
CURVE 10—ī in mī

ī shows 1700 cycles in special pattern picture. (Repeating).



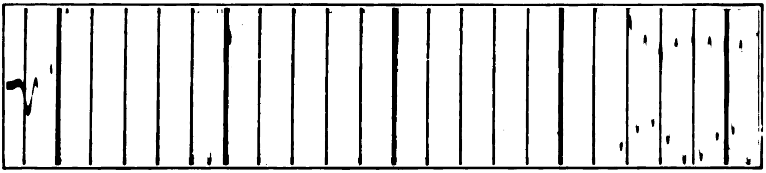
CURVE 11—ī in hĭ

í shows 2600 to 2700 cycles in special pattern picture. (Repeating).



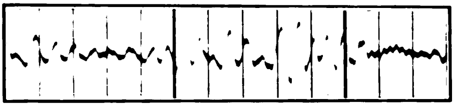
CURVE 12—j in Jōe

shows 3000 cycles for 0.01 sec., 2500 cycles for 0.05 second, 2000 cycles for 0.01 second in special pattern picture.



CURVE 13—k in kō

k shows special pattern picture.

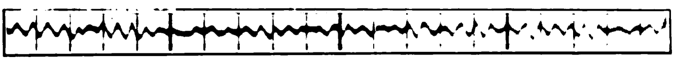


CURVE 14—l in lō

l shows alternation of 2500 and 1000 cycles per second in special pattern picture. (Repeating).

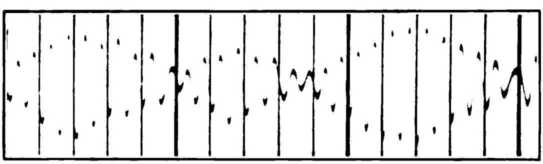
CURVE 15—m in mȳ

m shows 1200 cycles for 0.01 second, silence 0.006 second, 1200 cycles for 0.01 second in special pattern picture. (Repeating).



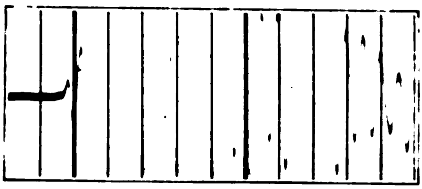
CURVE 16—n in nē

n shows 1100 cycles with silence following in special pattern picture. (Repeating).



CURVE 17—ō in tōe

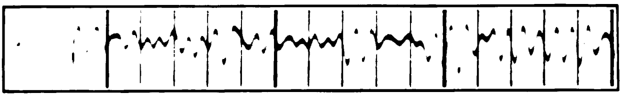
ō shows 1000 cycles in special pattern picture. (Repeating).



CURVE 18—p in pō

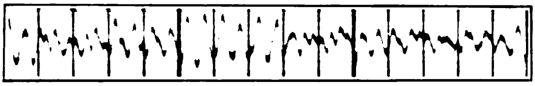
p shows special pattern picture.

q equals kyū.



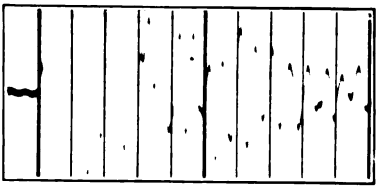
CURVE 19—r in rō

r shows alternation of 1000 and 1250 cycles in special pattern picture. (Repeating).



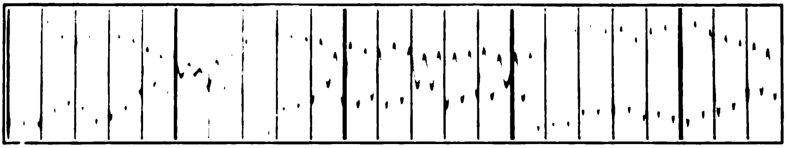
CURVE 20—s in say

s shows 1000 alternating with 2000 cycles per second superposed upon 1000 cycles per second. (Repeating).



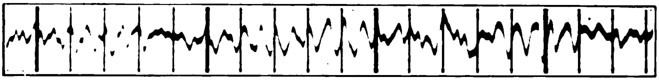
CURVE 21—t in tō

t shows special pattern picture.



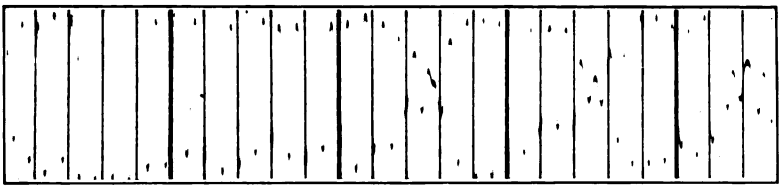
CURVE 22—ū in tū

ū shows 1100 cycles in special pattern picture. (Repeating).



CURVE 23—v in vē

v shows 1000 and 2500 cycles alternating in special pattern picture. (Repeating).



CURVE 24—ūō = w in wē

w in we, shows ū equals 1050 cycles; same special pattern as ū passing into ō equals 1000 cycles. (Repeating).

x equals ĕks

ȳ equals ū ī

y̆ equals ĭ

CURVE 25—z in zee

z shows 5000 and 2000 cycles per second alternating over 1000 cycles per second in special pattern picture. (Repeating).

From Helmholtz's formula for resonance of a spherical cavity with a small opening,

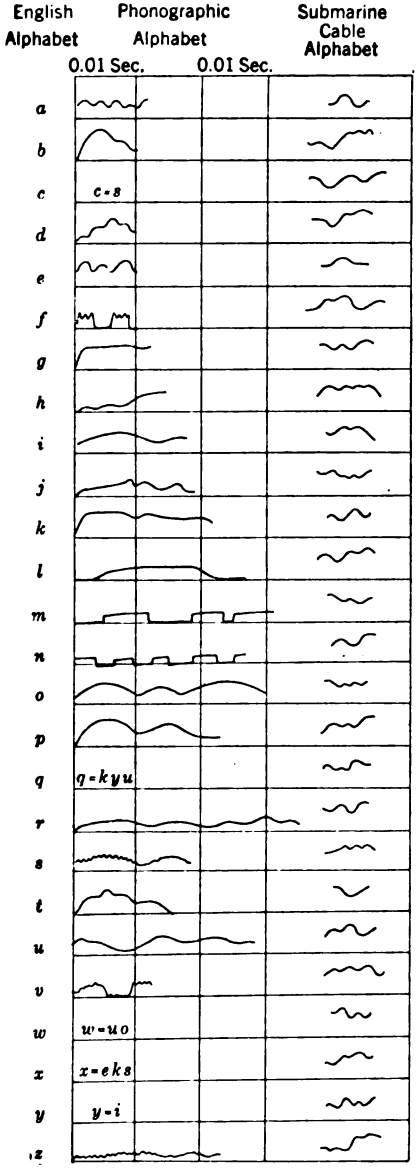
$$n = a\sqrt{\frac{3\,r}{8\pi^3\,R^3}}\,,$$

where n equals pitch of resonance of cavity,
r equals radius of opening of cavity,
R equals radius of cavity,
a equals 33,226 centimeters,
we can calculate the natural resonance tones of the mouth while uttering speech. I have done this and find that the resonance tones for the mouth vary from 800 to 3000 cycles per second, depending on the opening of the mouth. From our records, we find the pitches upon which whispered speech is uttered to be also from 1000 to 3000 cycles per second. This only shows, however, that pitch is an unavoidable characteristic of speech sounds. From the known facts, that a phonograph talking record may be run at more than twice the normal speed so that the speech tones must vary through more than a full octave and the speech is still quite intelligible, it is conclusive that pitch is not the main characteristic of speech sounds. That intensity variation is the main characteristic of speech sounds is well shown by the whispered speech records given, where no characteristic pitch is shown for b, d, g, k, p, t, but only definite pattern pictures. When the speed of the phonograph is increased, this pattern is shortened and distorted as we hear, but its main form is retained and we judge it as nearly the same as the sound at the correct speed and therefore are able to understand the speech. The pitch of speech sounds, then, only exists as a carrier of the speech-variations. In another paper not yet published on the Nature of Hearing and Perception, it is shown how pattern forms operate memory cells, and how we thus perceive the letter sounds of speech.

In general, the pattern form persists for at least 0.01 second and if the letter sound is sustained, the pattern repeats itself again and again. See pattern picture of letter ō sound, curve No. 17. One-hundredth second is the perception time. This is proved in the paper mentioned above. Therefore the mouth is a device for producing patterns of the necessary length and repeating them for sure perception.

Repetitions of pattern pictures of letter sounds (several times to make up a letter sound; see record of vowel ō, curve

No. 17,) are due to simultaneous excitatory and inhibitory action of impulses on same or opposing muscles in the mouth



or throat. At one moment excitatory impulse overbalances inhibitory impulse, then a maximum appears on the speech curve; when the excitatory and inhibitory impulses balance by interference (equal pull on muscle) no or little amplitude is shown on ō curve. "A slight and rapid muscle tremor is regularly produced by the simultaneous play of excitation and inhibition on one muscle, just as 'progression' and other rhythmic movements are regularly produced by the simultaneous play of excitation and inhibition on antagonistic muscle pairs. One muscle can actually receive excitatory and inhibitory influences simultaneously, and this condition results in a peculiar and characteristic muscle 'tremor'." (Sherrington C. S., "Nervous Rhythm," Proc. Roy. Soc., 1913, Ser. B, 86, 219-232; Forbes, A., "Reflex Rhythm induced by concurrent excitation and inhibition," Proc. Roy. Soc, 1912, Ser. B, 85, 289-298.)

The repeated use of patterns is the physiological basis of memory.

I conclude from an exhaustive search of 500 vowel and con-

sonant curves, that an accumulator or memory cell exists in the brain for each letter sound, detecting a definite picture

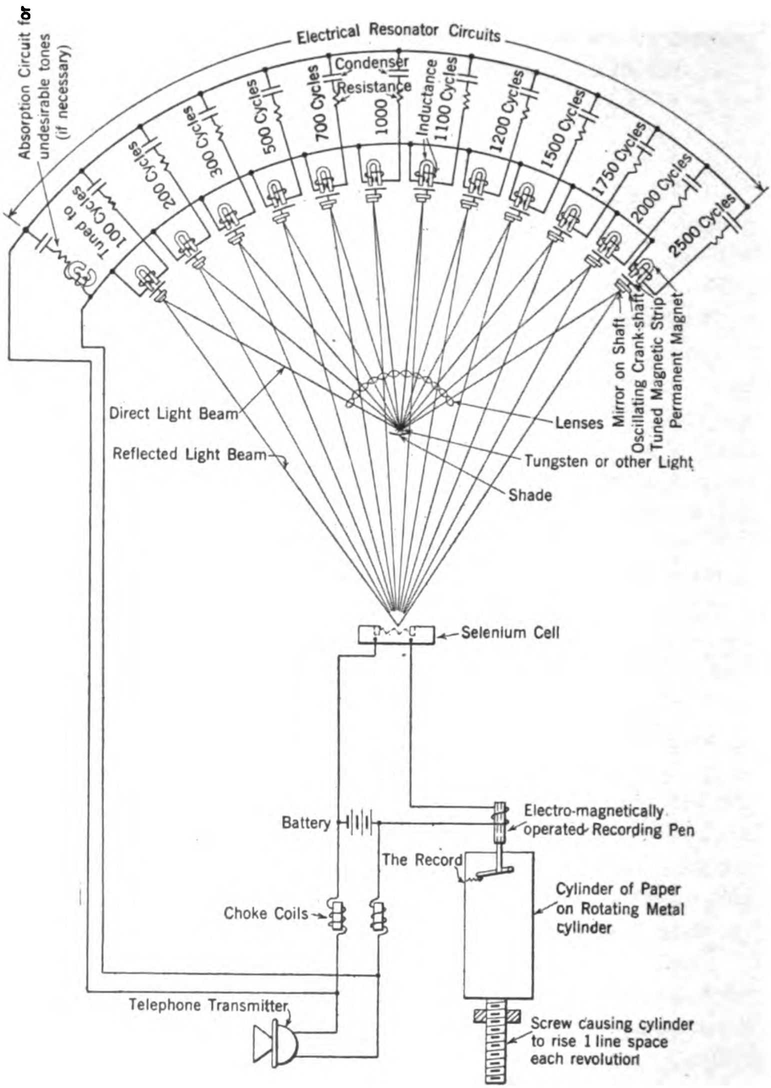


FIG. 1—GENERAL ARRANGEMENT AND WIRING DIAGRAM OF THE VOICE-OPERATED PHONOGRAPHIC ALPHABET WRITING MACHINE

pattern, such as that of the letter ō which has a simple character of varying amplitudes, but repeats this character or picture pattern about 100 times a second. Since it takes 0.01 second

to perceive a picture pattern (perception time for sounds), this seems the right length of time (0.01 second) for a definite picture pattern to last and then to have repetition.

Having shown that speech is made up of a set of pattern pictures of sound waves called the phonographic alphabet, it seemed feasible to design and construct a machine which would record speech automatically in ink on paper in the form of this

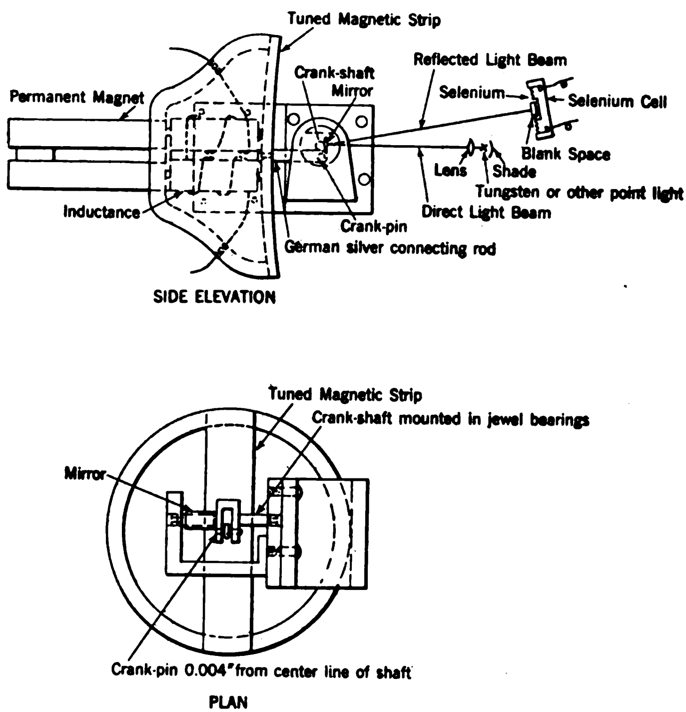


FIG. 2—MECHANICAL ARRANGEMENT OF MIRROR-MOVING MECHANISM OF THE VOICE-OPERATED PHONOGRAPHIC ALPHABET WRITING MACHINE

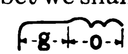
easily read compact system of natural characters called the phonographic alphabet. This machine has been carefully designed and will be completed in the near future.

VOICE-OPERATED PHONOGRAPHIC ALPHABET WRITING MACHINE

Fig. 1 shows a wiring diagram and general arrangement of the elements of this machine. Notation on the sketch explains the function of the different parts of the device. Fig. 2, in

plan and elevation, shows the mechanical arrangement of each electrical resonator circuit and how the resistance of the selenium cell is varied by the differences in the amount of light coming from the vibrating mirrors.

Method of Operation. On reference to Fig. 1, it is evident that by talking into the telephone transmitter, speech currents are caused to flow into the electrical resonator circuits. An audion may be used as a relay if desired, to increase the strength of the voice currents. That resonator which is tuned to the main tone of the speech at any instant, will respond, the current existing in it at any moment varying in strength according to the speech-variation. The magnetic strip placed over the poles of the electrical resonator magnet will vibrate powerfully (if the electrical tuning of the electrical circuit and the mechanical tuning of the magnetic strip are of the same tone as the tone of the speech). On reference to Fig. 2, it is seen that the vibrating magnetic strip causes the connecting rod to oscillate the tiny shaft held in jewel bearings. The connecting rod is pinned to the tiny shaft only 0.004 in. from the center line of the shaft. In this way, a motion of the magnetic strip of 0.0001 in. will cause angular motion of the tiny shaft of 1½ degrees. A mirror fixed to this tiny shaft will oscillate with it and cause the beam of light from the tungsten or other lamp to be reflected onto the selenium cell. In the normal position of rest the mirror reflects the light beam onto a blank space at the middle of the selenium cell box where it has no effect on the selenium cell. When the reflected beam of light oscillates, both parts of the selenium cell on each side of the blank space will be illuminated and the resistance of the selenium will be decreased, allowing more current to pass through it from the battery and causing the electromagnetic recording pen to trace a wavy line on the paper sheet fastened to the revolving platen.

To illustrate the method of operation: Let the word "go" be spoken into the telephone transmitter. From our table of the letters of the phonographic alphabet we shall expect the recording pen to write "go" in the form of 

. It is known from my research that there are present in the sound of a man's speech, principal tones of 100 cycles per second (the fundamental tone of a man's voice), 200 cycles per second (the 1st overtone of the man's voice), and a tone of approximately 1000 cycles per second (the resonance tone of the mouth for the o-position.) These three tones will be moulded or varied in intensity simul-

taneously by the muscles of the throat and mouth, first in the g-form (a sudden explosion of the three tones) and then in the o-form (a quick waxing and waning of the three tones.) Three tuned electrical resonating circuits marked respectively 100, 200 and 1000 cycles will simultaneously respond to the three tones and three beams of light will oscillate over the face of the selenium cell, each vibrating after the same pattern at the same instant of time. The current in the selenium cell and in the recording-pen magnet will vary in strength, first according to the g and then to the o-form, causing the writing in ink on the rotating paper cylinder of  . In the same way, all letter sounds are written and we thus have a visible-writing machine recording our thoughts as rapidly as we speak, in the natural alphabet.

This work was conducted by cooperation of the Dept. of Physiology, College of Physicians and Surgeons, New York, and the Underwood Typewriter Co.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 8, 1916.

NOTES ON THE MEASUREMENT OF HIGH VOLTAGE

BY WILLIAM R. WORK

Abstract of Paper

A brief account is given of some experiments made to determine the relative accuracy of certain methods used in measuring high voltages.

The methods comprise the use of a tertiary (or voltmeter) coil in the high-tension transformer, the direct measurement of voltage by a crest voltage meter and the derivation of the high-tension pressure from the primary voltage.

In most commercial and experimental tests employing high voltage a knowledge of the crest or peak value of the voltage is of the first importance. Often this crest value may be determined quite satisfactorily by a gap method. In other cases (dielectric tests on cables, etc.,) the use of a spark-gap is not desirable because the discharge of the gap may set up oscillations which will over-stress the dielectric thereby permanently injuring or even puncturing it.[1] There are other well known disadvantages attendant on the use of a spark-gap as a voltmeter. Several methods for the measurement of high voltages which are free from the objections peculiar to the spark gap have been used.

This paper is an account of some tests which were made with the view of comparing these methods among themselves and with a spark gap.

Experimental Apparatus

The generator used is a 60-kv-a., 250-volt, eight-pole, 60-cycle, three-phase alternator with both ends of each phase winding brought out to the terminal board. In these tests the excitation was kept substantially constant at normal value and three schemes of connection were used giving three different classes of voltage waves. These schemes will be designated *Supply A*, *Supply B* and *Supply C* respectively.

Manuscript of this paper was received January 12, 1916.

1. *Voltage Testing of Cables*, Middleton and Dawes, Proc. A.I.E.E., June, 1914, page 1006.

Supply A. Windings connected in Y. Wave shape approximating a sine form. See Fig. 1.

Supply B. One phase winding alone. Prominent third harmonic with other harmonics giving a flat-topped wave. See Fig. 1.

Supply C. Two windings connected in V. Same fundamental as *Supply B* but the third and ninth harmonics are doubled in value and the wave has a prominent hollow at the quarter-cycle point. See Fig. 2.

The transformer has a capacity of 100 kv-a. at 200,000 volts, 60 cycles. One end of the high-tension winding was grounded. The primary winding consists of four separate 480-volt coils arranged to be connected in parallel, in series-parallel or in series. The reactance drop is about 4.5 per cent, the resistance

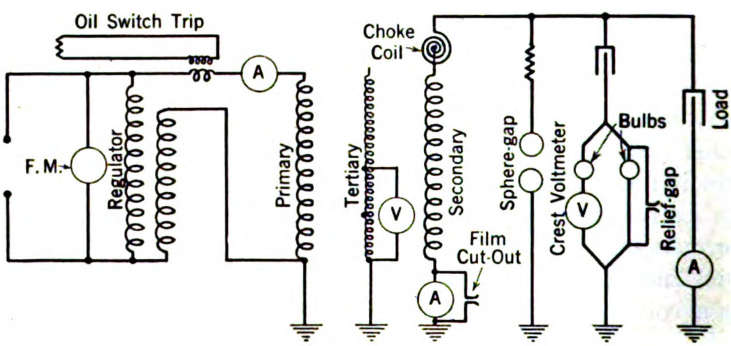
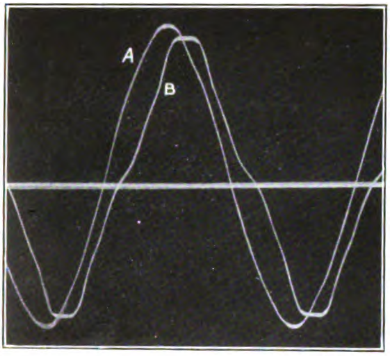


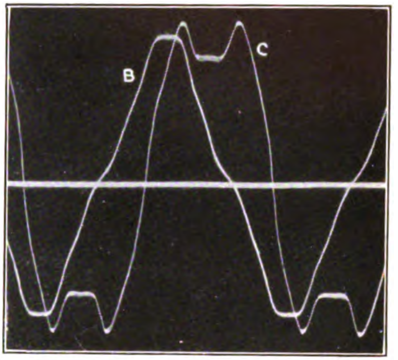
FIG. 4

drop about 0.6 per cent. Due to the capacitance of the high-tension winding the no-load power factor of the transformer is high, varying from about 99 per cent to about 96 per cent, over the range of voltage used in these tests. The transformer had been equipped with a tertiary, or voltmeter, coil intended to serve as a means of determining the secondary voltage. This coil has taps brought out at 25 per cent and at 50 per cent of the winding. The accuracy with which the secondary voltage could be determined by the use of this coil was one of the things investigated.

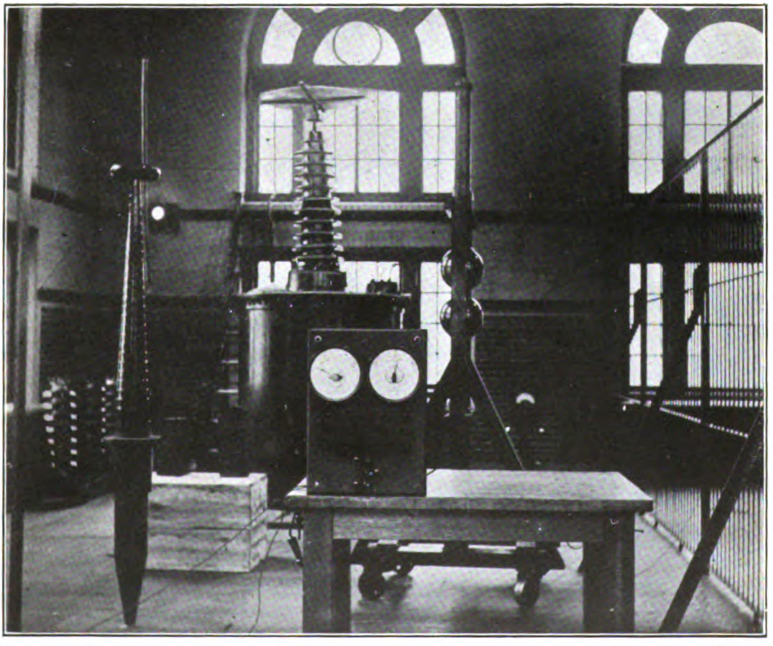
Control of the voltage was obtained by a 50-kv-a., 60-cycle induction regulator with which the pressure applied to the transformer primary could be varied from zero to twice the generator voltage in a satisfactory manner.



[WORK]
FIG. 1—NO-LOAD WAVE FORMS OF SUPPLIES A AND B



[WORK]
FIG. 2—NO-LOAD WAVE FORMS OF SUPPLIES B AND C



[WORK]
FIG. 3—TRANSFORMER, SPHERE GAP AND CREST VOLTAGE METER

Voltmeters of the electrodynamometer type were used, all being checked against the same precision voltmeter. The larger secondary currents were measured by a hot-wire ammeter; smaller currents, by voltmeters used as ammeters.

For the tests with condensive load, sixty $\frac{1}{4}$-mf., 2000-volt condensers were available. These were used in two different combinations, *viz.*, all in series, and thirty in series, two in parallel.

The actual secondary voltage was determined by a standard 250-mm. sphere gap. The relation between the length of gap and voltage and the correction for air density as specified in the Standardization Rules of the Institute were used. Incidentally, the air density correction factor, k, for 250-mm. spheres, corresponding to a barometric pressure of b mm. and an air temperature of t deg. cent., can be expressed as a function of b and t thus:[2]

$$k = \frac{0.366\ b}{273 + t} + 0.066$$

In most of the tests the gap was set at a certain length and the voltage slowly raised until spark-over occurred; in some cases, however, the gap was shortened slowly with the voltage constant. There was little difference in the results obtained by the two methods of manipulation although the first method gave slightly more consistent results and was therefore preferred. In using the gap a set of observations was considered good only when the voltmeter (on the tertiary coil) indicated stable conditions at the moment of breakdown. Each point is the mean of five to seven trials.

Determination of Crest Factors

Polar oscillograms of the voltages and currents were taken and the first six odd harmonic components of the waves were determined by a mechanical analyzer.[3] The crest values were then obtained by calculating the ordinates of the waves at a few degrees on either side of the angle at which an inspection of the oscillogram indicated the peak. The crest values thus determined from the harmonic components were checked by direct measurement of the amplitudes on the oscillograms.

2. Derived from Peek's eq. (4), page 897, Proc. A.I.E.E., June, 1914.
3. *Electric Journal*, Feb. 1914, May, 1914.

TABLE I—SECONDARY VOLTAGE DERIVED FROM TERTIARY VOLTAGE

(Secondary pressure derived from the observed tertiary voltage and expressed as the r. m. s. value of the sine wave of equal peak.)

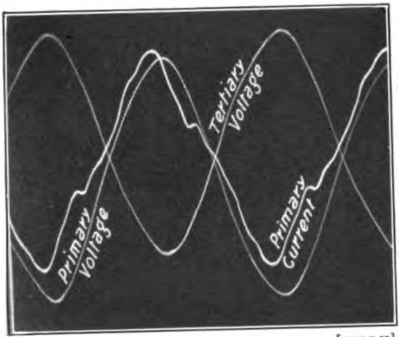
Ratio of secondary turns to tertiary turns = 1000 : 1

Test	1	2	3	4	5	6	7	8
Supply	*A*	*A*	*A*	*A*	*B*	*B*	*C*	*C*
Secondary current (amp.)	0.024	0.035	0.114	0.342	0.031	0.110	0.0306	0.323
Tertiary r. m. s. volts × 1000 = E_3	99,300	95,400	68,900	59,000	86,000	63,300	56,100	48,600
Crest factor of tertiary voltage ÷ $\sqrt{2}$ = F_3	1.026	1.024	1.011	0.968	1.127	1.067	1.017	1.212
R. m. s. value of sine of equal peak of ter. volts × 1000 = $E_3 F_3$	101900	97,700	69,700	57,100	96,900	67,500	57,100	58,900
Secondary volts by gap. R. m. s. value of sine of equal peak = E_2	103700	96,900	69,300	57,600	96,600	67,400	57,900	57,600
Per cent error by (*a*) r. m.s. ter. volts alone	—4.2	—1.5	—0.6	+2.4	—11.0	—6.1	—3.1	—15.6
(*b*) ter. volts corrected for crest factor	—1.7	+0.8	+0.6	—0.9	+0.3	+0.2	—1.4	+2.3
Figures	5	6	7	8, 13	9	10	11, 14	12, 15

An inspection of the above data shows that the tertiary voltage *corrected for crest factor* is a satisfactory measure of the actual secondary voltage as determined by a sphere gap.

Obviously the r.m.s. value of the tertiary voltage should not be used alone as a measure of the secondary voltage, when the latter is defined in terms of the crest value, unless something is known about the crest factor. The wave shape of the secondary voltage depends upon so many factors of complex relationship that it is practically impossible to predict how the crest factor will be changed by a given change in the conditions of load or supply. The condensive character of the usual load in combination with one or more of the several inductances of the system may result in the amplification of one of the higher harmonics through partial, if not full, resonance, or it may result in suppression of the higher harmonics. Magnetic saturation in the generator, control apparatus and the transformer plays an important part in wave distortion, while corona, by changing the value and phase of the current, may contribute to the effect through generator reactions.

In this connection it is interesting to study the oscillograms and the crest factors of the voltage waves. In tests 1 to 4 (Figs. 5 to 8) the generator was connected to give a "good" e.m.f. wave (Supply *A*). As the load was increased the tertiary voltage wave shape changed from a peaked form to a



[WORK]

FIG. 5—TEST No. 1

Crest factor of primary voltage = 1.421
Crest factor of tertiary voltage = 1.451

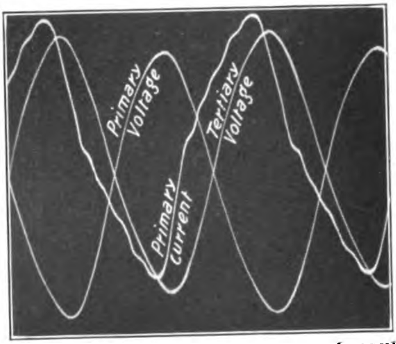


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FIG. 6—TEST No. 2

Crest factor of primary voltage = 1.434
Crest factor of tertiary voltage = 1.448

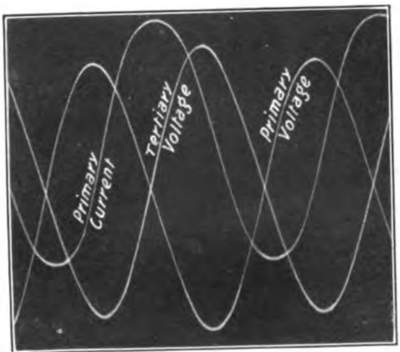

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FIG. 7—TEST No. 3

Crest factor of primary voltage = 1.424
Crest factor of tertiary voltage = 1.430

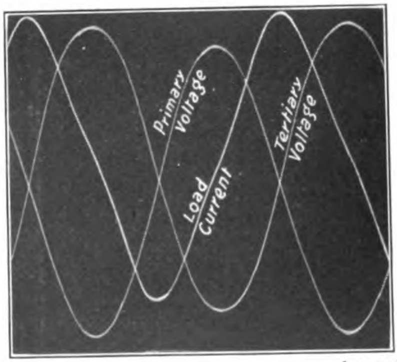

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FIG. 8—TEST No. 4

Crest factor of primary voltage = 1.414
Crest factor of tertiary voltage = 1.369
Crest factor of integral of load current = 1.373

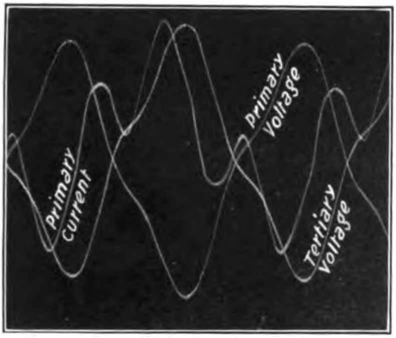

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FIG. 9—TEST NO. 5

Crest factor of primary voltage = 1.581
Crest factor of tertiary voltage = 1.593

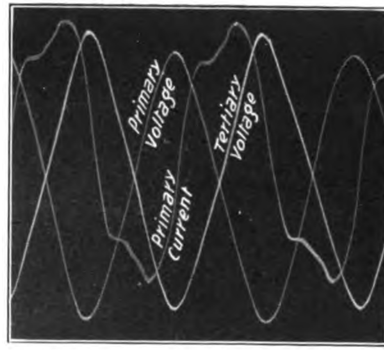

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FIG. 10—TEST NO. 6

Crest factor of primary voltage = 1.474
Crest factor of tertiary voltage = 1.509

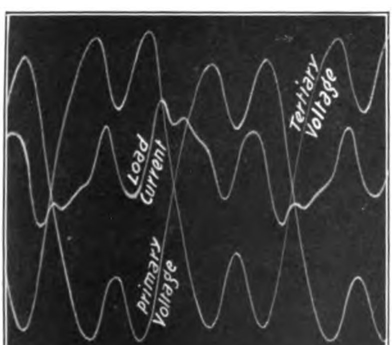

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FIG. 11—TEST NO. 7

Crest factor of primary voltage = 1.399
Crest factor of tertiary voltage = 1.438
Crest factor of integral of load current = 1.528

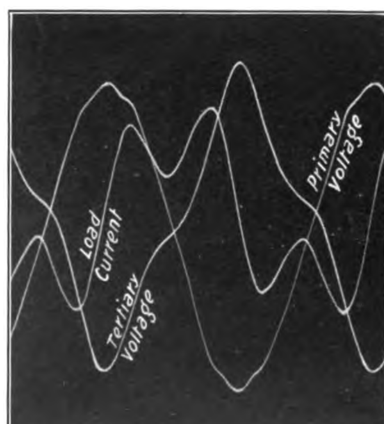

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FIG. 12—TEST NO. 8

Crest factor of primary voltage = 1.437
Crest factor of tertiary voltage = 1.714
Crest factor of integral of load current = 1.655

flat-topped form, the crest factor varying apparently as a linear function of the secondary current. In tests 5 and 6 (Figs. 9 and 10) Supply B was used. The chief impurity in these tertiary wave shapes is the third harmonic. This component was 19.2 per cent of the fundamental with the lighter load but only 6.5 per cent with the heavier load, the resulting change in the crest factor being from 1.593 to 1.509. The addition of load here reduced the crest factor. Figs. 11 and 12 (tests 7 and 8) are especially interesting in that they show great changes in wave shape and crest factor produced by simply changing the load. The chief impurity in the tertiary wave shape is again the third harmonic. Here an increase in the load lowered this component in value from 36 per cent to 24 per cent, and, what is of more importance, practically reversed its phase, resulting in a change in the crest factor from 1.438 to 1.714.

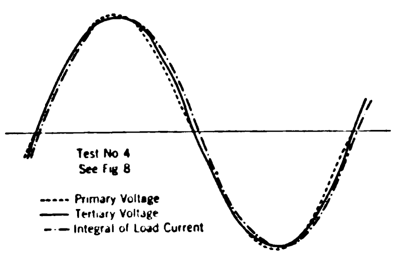

FIG. 13

The addition of load in this case therefore increased the crest factor.

There is some evidence that the tertiary voltage wave form is more likely to resemble the secondary voltage wave form than the wave form of the primary voltage. No attempt was made to determine the high-tension wave form directly, but in three of the tests this wave shape was derived by integrating the current through the condensive load expressed as a harmonic series. Dividing this integral by the capacitance of the load gave the harmonic series representing the secondary terminal voltage. Figs. 13, 14 and 15 compare the several voltage waves as mechanically synthesized from their respective harmonic series. The scale of these figures is so chosen that all the waves have the same r.m.s. value. The secondary wave shape determined in this manner is not strictly correct, on account of some corona current which was present. By inte-

grating the whole load current and thus ignoring the in-phase component due to corona the resulting wave is made to appear to the right of the true curve; and, further, since the shift of the fundamental is proportionately greater than for the higher harmonics, the shape of the wave is affected. This error is especially noticed in Fig. 14, where the capacitance of the load was the smallest and the corona current therefore largest as compared to the condenser current. Fig. 15 shows a marked difference between the primary voltage wave and the secondary voltage wave obtained by integration, but the latter wave is in fair agreement with the wave of tertiary voltage.

These tests, few as they are, show the necessity for a knowledge of the crest factor *under the particular conditions of the test* in order to use the voltage of a tertiary coil as an accurate measure of the secondary voltage.

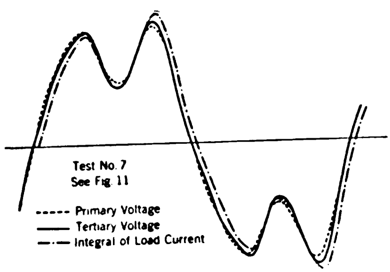

FIG. 14

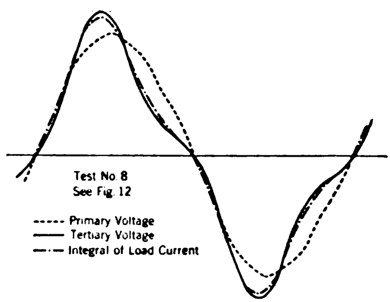

FIG. 15

SECONDARY VOLTAGE MEASURED BY CREST VOLTMETER

Crest voltmeters having indications dependent upon the average value of the charging current taken by a condenser and thereby measuring the peak value of the voltage across the condenser have been used in experimental testing.[4] In order to learn something of the usefulness of these meters under conditions prevailing in ordinary high-tension testing, a meter of this type was also used to measure the high-tension pressure, in all but test 1.

4. Calibration of the Sphere Gap Voltmeter, Chubb and Fortescue. TRANS. A.I.E.E., 1913, Vol. XXXII, page 739.

The Electric Strength of Air, Whitehead and Gorton. PROC. A.I.E.E., June, 1914, page 920.

For clearness the observations are here exhibited in a separate table.

TABLE II—SECONDARY PRESSURE MEASURED BY CREST VOLTMETER AND EXPRESSED AS THE R.M.S. VALUE OF THE SINE WAVE OF EQUAL PEAK

Test	Supply	Crest voltmeter reading	Sec. volts by gap r. m. s.	Sec. volts by integ. load cur.	Error of crest voltmeter per cent
2	*A*	96,600	96,900		−0.3
3	*A*	69,600	69,300		+0.4
4	*A*	57,500	57,600	57,400	−0.2
5	*B*	96,400	96,600		−0.2
6	*B*	68,300	67,400		+1.3
7	*C*	82,700	57,900		+42.8
8	*C*	56,900	57,600	57,100	−1.2

The measurement of high voltages by this method has substantially the simplicity of the ordinary methods for low voltage, with a precision apparently limited only by the difficulties of original calibration, save in one respect. Meters of this type, employing rectifying bulbs, are inherently incapable of giving indications proportional to the highest peak of a voltage wave which has several peaks in a half-cycle. With waves of this kind the current through the condenser will have both positive and negative lobes in a half-cycle. Now the crest value of the voltage is proportional to the maximum quantity of electricity in the condenser, and this quantity is proportional to the net area of the current-time curve for one half-cycle, negative lobes counting as negative areas. The permanent magnet type instrument in series with a rectifying bulb indicates the average positive current throughout a whole cycle and thus measures the sum of the areas of all the positive lobes of the current-time curve in a whole cycle, failing to subtract the areas of the negative lobes when these are present in the first half-cycle and adding the areas of the same lobes when they appear on the positive side in the second half-cycle. The error is therefore a double one, both elements causing the meter to measure a current greater than the true average current and therefore to indicate a voltage greater than the true high-tension voltage. Test 7 (Fig. 11) shows a case in which an extreme effect of this kind was purposely obtained by resorting to the use of Supply C. Distortions of this degree are difficult to produce and are not likely to occur in practise.

An error of another kind will be introduced in the measurement unless the frequency of the e.m.f. being measured is the same as the frequency employed in the original calibration of the meter. Since with a constant e.m.f. the meter reading will vary directly as the frequency, the proper correction can be easily applied.

TABLE III—SECONDARY VOLTAGE DERIVED FROM PRIMARY VOLTAGE

(The secondary pressure expressed as the r. m. s. value of the sine wave of equal peak is assumed equal to r. m. s. value of primary pressure multiplied by the ratio of its crest factor to $\sqrt{2}$ and by the ratio of turns.)

Test	1	2	3	4	5	6	7	8
Supply	*A*	*A*	*A*	*A*	*B*	*B*	*C*	*C*
Sec. currents (amps.)	0.024	0.035	0.114	0.342	0.031	0.110	0.0306	0.323
Primary r. m. s. volts = E_1	238.4	228.5	160.0	247.9	205.4	146.6	265.7	198.5
Pri. voltage crest factor ÷ $\sqrt{2}$ = F_1	1.005	1.014	1.007	1.000	1.118	1.042	0.989	1.016
Ratio of turns = K	417	417	417	208	417	417	208	208
Calculated sec. volts = $E_1 F_1 K$	99,900	96,600	68,700	51,700	95,700	63,700	54,700	42,000
Sec. volts by gap, r. m. s.	103700	96,900	69,300	57,600	96,600	67,400	57,900	57,600
Per cent error	−3.7	−0.3	−0.9	−10.2	−0.9	−5.5	−5.5	−27.1
Figures	5	6	7	8, 13	9	10	11, 14	12, 15

As would be expected, the primary voltage, even when corrected for crest factor, is not, in general, a satisfactory measure of the secondary voltage, largely because the wave form of the primary voltage may or may not resemble the wave form of the secondary voltage under given circuit conditions, the difference being especially noticeable in Fig. 15. Of course the use of the simple ratio of turns is responsible for part of the error, because the internal resistance and reactance drops in the transformer are thereby neglected.

Conclusions

For the conditions of test and with the apparatus used, the following conclusions may be drawn:

It is possible to wind in a high-tension transformer a tertiary (or voltmeter) coil in such a manner that the voltage induced in this tertiary coil, when corrected for crest factor, is a satisfactory measure of the secondary terminal pressure.

A crest voltmeter provides a convenient and, in general, an accurate means for measuring high voltages, though errors can be introduced by the use of extremely distorted voltage waves.

The primary voltage, even when corrected for crest factor, is an uncertain measure of the secondary voltage because the respective wave forms may differ.

DISCUSSION ON "PHYSICAL LIMITATIONS IN D-C. COMMUTATING MACHINERY" (LAMME), SAN FRANCISCO, CAL., SEPT. 16, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915.)

(Subject to final revision for the Transactions.)

E. H. Martindale: The point impressed on me with the greatest emphasis was in connection with the use of the soft graphitic brush for high-speed machines and with machines having solid commutators. It is a misnomer. The brush to be used on the solid commutator need not be soft. It must be non-abrasive, but one of the hardest brushes manufactured in this country has no abrasive action and is used very extensively on undercut commutators and on speeds up to 6000 ft. per min. I want to emphasize the distinction between hardness and abrasiveness, and point out the fact that this has no relation to the softness or graphitic nature of the brush.

Mr. Lamme speaks of getting a decrease in contact drop of as much as one-half or one-third of the cold contact drop. We had never found anything like as great a drop as that in an un-impregnated brush. If we take an impregnated brush, one soaked in oil or paraffine, we get a contact drop of around 3.3 and 5 volts to the two brushes in series. Then if we heat the brush enough to drive the oil back from the surface and leave the contact surface of the brush dry, that drop will go down to 1.6, a reduction of more than one-half. I have never found more than 0.15 of a drop, even with temperatures almost to the blowing point, if the brush has not been previously impregnated.

I believe that one of the most pronounced limiting features in the design of d-c. machinery is the friction of the brush. As brushes have been improved the commutator speeds have gone up. They go as high as possible—Mr. Lamme mentions one of about 7000 ft. per min. That would have gone up to 9000 ft. per min. if the brush would have worked. By the time a brush is made that will work to 9000 ft. per min., they will get the commutators. If a machine can be doubled in speed, the output can be almost doubled without very many changes in the copper or iron in the machine. In the case of the brushes manufactured up to eight or ten years ago, 5000 ft. per min. would have been impossible. The old carbon brush, as we called it, would not stand speed above 4000 ft., without the brush chattering, chipping and causing all sorts of trouble.

H. R. Summerhayes: I wish to discuss the subject of flickering of light supplied from d-c. generators, mentioned in Mr. Lamme's paper. This subject is of particular importance in small or medium size isolated plants. Experiments I have seen made, indicate that the drop in voltage is according to the percentage of load thrown on the generator, that is, the percentage of fluctuation of load as compared to full load, on generators of the non-compensated type. It is generators of this type which are generally in service for office buildings and hotels.

Mr. Lamme states that a 10 to 15 per cent increment of load thrown suddenly onto a generator will cause a flickering in the lights. We have found, perhaps, a little greater variation with different types of generators. I should say that it is 10 to 20 per cent, which agrees pretty closely with Mr. Lamme's figures. Therefore, if you have a 150-kw. generator, and start an elevator taking 50 kw. as the high-speed elevators do, you have a one-third load thrown on suddenly, and as this is about double the flickering limit, such plants must always show a perceptible flicker.

In larger plants where a single elevator forms a smaller proportion of the total load of one generator the flickering is not so perceptible, although there are more elevators. That is, because it is impossible to start two elevators at the same time. I mean exactly at the same time, and even if they are started 1/50 of a second apart, the effect is very different from what it would be if they were started simultaneously.

Mr. Lamme discusses non-periodic fluctuations. I have seen experiments which indicated that as low as 1 per cent variation, requiring over half a second for the change, will not cause a noticeable flicker to the average observer, but if the duration of the fluctuation is shorter than half a second, or the voltage variation greater than 1 per cent, it will cause a perceptible flicker. That is only when the observer is watching for the flicker. If one is simply reading or working, with his attention concentrated on his work, the flicker would have to be more than that, to be perceptible. Probably two or three volts fluctuation, in a half-second, would be annoying to readers and would cause complaint. I would like to ask Mr. Newbury to explain a little further the theory which he mentioned, where a resistance is connected across the circuit, 100-volt generator, and 100 amperes going through the resistance. Now, a second resistance is connected across, and in order to have the drop of 50 volts, as Mr. Lamme said, the current would have to divide equally, 50 amperes in each resistance. In this case an oscillograph connected in series with the first resistance should show a momentary reduction of current from 100 to about 50 amperes. Is this result shown by the tests?

Gano Dunn: I find that Mr. Lamme's paper does not refer to a certain principle of commutation with which I have had considerable experience, and which I regard as very important. It is a principle which has not been successfully reduced to practise, for reasons which I believe are wholly of a mechanical origin and I believe will be ultimately overcome.

A commutating machine arranged on this principle invented by Mr. F. W. Young some years ago, has been in service for four or five years. A number of them have been built and used, in some cases with very marked success, but in general without sufficient success to take a place commercially. The principle to which I refer is involved in the question of the contact drop

of the brush. Mr. Lamme says regarding the subject of the contact drop, " This peculiar property of the brush contact is, in some ways, very much of a disadvantage." Now, a thing that is a disadvantage, in some ways, is often made of very great advantage if you change the ways in which it is a disadvantage. The principle I refer to consisted in so changing the ways that the disadvantage of contact drop is turned into an advantage that produces unusually perfect commutation.

You all have been familiar with various ways of killing sparks. Imagine a circuit with considerable inductance opened by a single-pole, single-throw knife-switch. The spark if it occurs can be killed by shunting a high resistance around the switch. The high resistance around the open switch, while it reduced the spark, never completely killed it, but always left it, while smaller, with a good deal of vigorous spiteful life.

Another way of killing sparks is to put a condenser around the same switch. The condenser, if large enough, is better than high resistance, but even the condenser leaves some portion of the spark which cannot be completely killed and the portion it leaves is the most annoying portion.

Another way is to shunt around the switch, e.m.f. A counter e.m.f. is a better way than either of the two previous methods for killing spark, and as a rule it kills it so completely that you can hardly see it. As a confirmation of the law, there is very little spark when opening a circuit that is charging a storage battery. The phenomenon is the same and due to the same cause, because the counter e.m.f. of the storage battery or the other source of counter e.m.f. around the switch opposes the e.m.f. of self-induction and kills the spark by what I might call neutralization.

Now, in commutation the drop contact between the brush and the commutator, no matter what it is due to, acts almost exactly like a counter e.m.f. It has all the characteristics, in fact, so much so that it is often called the counter e.m.f. of contact, and whether it is a counter e.m.f. of contact or not, it very naturally looks and acts in a similar manner. The function of commutation is to accelerate the reduction of the current, so that by the time a commutator bar gets to the edge of the brush, the current will have been so greatly previously reduced that when the contact is broken, there will be no spark.

Now, one way of doing that has been by means of the resistance in the leads, which Mr. Lamme has described. Another way of doing it is by the fringe of e.m.f. produced by the pole tips. A counter e.m.f. created in the commutating coil, tends to neutralize the current and stop it before the commutator bar leaves the brush. That is obtained by shifting the brushes. If, however, we could introduce into that path of current, between the carbon brush and the bar, a gradually increasing counter e.m.f., that gradually increasing counter

e.m.f. would tend to stop the current not only just as well as the counter e.m.f. introduced in the coil by the pole fringe, and just as well as the counter e.m.f. due to the drop across the resistance leads tends to do it, but it would do it better than either. Just in the same way that a high-resistance shunt around the knife switch only reduces the spark but does not eliminate it and still leaves it with vicious character, so the high-resistance leads reduce the spark but do not remove it but leave it with vicious character; but when you can accomplish that result with counter e.m.f. the character of the spark that is left is different. If you have enough counter e.m.f. the spark is completely removed. How can we introduce into the path of the current between the brush and the commutator bar additional counter e.m.f.? It can easily be done by adding a brush made of the same material as the original brush and put along next to it and insulated from it, so that the current that is in the one cannot go to the other in any way except by going down into the commutator. Then you will notice where you formerly had, say, 1 volt counter e.m.f. between the carbon brush and the bar, a time will come when you will cause the current to go down out of the brush into the bar, then up into the other brush, and down into the commutator, causing 3-volt counter e.m.f. to be inserted into the circuit where formerly you had only 1 volt. In doing that you have performed a remarkable feat in the acceleration of the turn-over of a particular coil. In practise it is astonishing how well that works. Not only is this principle good for the additional one, what might be called the "dead" brush, but it is suitable to work with the addition of two or three more brushes. The principle admits of considerable expansion. You may ask why has not this come into more practical use if it is so effective? The reason is that these brushes do not wear evenly in practise, and if one wears a little more than the other, then you do not get the same uniform contact. If brush holders can be designed that will permit the wear of the brushes, then the results obtained by this method of commutation are marvelous.

The commutators polish beautifully, and the whole characteristics of commutation are different. I have known generators of, say, 500 kw., or over, running at 600 volts, to run several years with one set of these brushes. The great enemies to these brushes are overloads and short-circuits. The high voltages that often occur, no matter what commutation you have, burn the brushes and the insulation between them, and so interfere with this triple path. It is no longer perfect, you have the effect of only one brush as before; and the dead brush is a hindrance instead of a help.

F. D. Newbury: In Mr. Martindale's discussion he very correctly pointed out that hardness and abrasiveness in carbon brushes are not necessarily coincident properties. However, the important point, as I attempted to point out, is not whether

a brush is soft or hard, non-abrasive or abrasive, but whether that brush is capable of carrying the largest current per square inch of contact surface, and I think Mr. Martindale will agree that the maximum current carrying capacity is usually found in a graphitic brush, and a graphitic brush is usually non-abrasive, so we have the under-cut commutator. We do not use the non-abrasive brush because the commutator is under-cut, but we under-cut the commutator so that we can use the large current-carrying brush which means, in general, a non-abrasive brush. The decreased contact drop mentioned in Mr. Lamme's paper was found in the case of a large number of commercial brushes, both American and foreign, and in no case, as I remember the experiments, was an impregnated brush used. We all know that impregnated brushes are good until you use them; in other words, as soon as they heat up in service the effect of the impregnation is very largely lost. But this extreme change in contact drop or temperature was found with ordinary commercial brushes, both hard and soft brushes, and was observed experimentally by heating the collector ring by external means so that it had nothing to do with the character of the surface or of the action of commutation. These large drops were a surprise and I really believe explain many of the anomalous results we have obtained in using the same brush on different machines and using different brushes on the same machine.

The permissible peripheral speed is not only a function of the brushes, but is to a large degree determined by mechanical limitations in the design of the commutator. As an illustration of this, the highest peripheral speeds in use are on high-voltage machines with small current capacity and consequently having short commutators. The brushes used on such machines work very well up to 6000 or 7000 feet and would work just as well on a very long commutator if it could be designed so that it would operate without deformation. So the brush characteristics are not the thing that stands in the way of still further increase of peripheral speed in the majority of large machines.

Mr. Summerhayes's question as to the explanation of what really happens when the load is suddenly changed, may be answered by pointing out that he is correct if certain things happen first, and Mr. Lamme is correct if other things happen first. Whichever theory is accepted it must square with the facts.

I think we all started with the idea that the different results as to flicker obtained under different conditions, or in different installations, were influenced largely by the type of generator, but oscillograms that had been made from all types of machines, ranging from the low-speed non-commutating pole type to the high-speed commutating pole compensated type, have all shown the same characteristic results. As Mr. Summerhayes pointed out, the amount of the dip in voltage is a function of

the percentage change in load. There is a table of results given in Mr. Lamme's paper illustrating this fact. The same dip in voltage is obtained with, say, 80 amperes change from half load, as with 160 amperes change from full load; also a different change in voltage is found with the same load change from different initial loads. This shows, I think, the correctness of the explanation given in the paper. If Mr. Summerhayes's explanation were correct, we certainly should find a considerable quantitative difference with different types of generators. I would expect particularly, a radical difference in voltage change between non-compensated generators and compensated generators, a condition that has not been shown by the tests with which I am familiar.

I am very glad that Mr. Dunn brought out the points he did in regard to commutation. Of course, Mr. Lamme's paper is not complete, no paper on commutation can ever be complete—and it is very desirable to have the additional information which Mr. Dunn has given, brought into the record. The paper does not say that contact drop is a disadvantage, as Mr. Dunn apparently believes; the disadvantage is that the contact drop increases so slowly with increased current. Commutation in the ordinary machine would be impossible without a large contact drop at the brushes and commutation would be very much better if that contact drop increased in proportion with the current, but it only increases slowly, so that with double load the short-circuit current may be greatly increased, which would not be the case if the contact drop increased in proportion with the load.

DISCUSSION ON "AUTOMATICALLY CONTROLLED SUBSTATIONS" (ALLEN AND TAYLOR), SAN FRANCISCO, CAL., SEPT. 16, 1915. (SEE PROCEEDINGS FOR SEPT., 1915.)

(Subject to final revision for the Transactions)

A. H. Babcock: Some years ago when a rather large mountain railway electrification was being studied, an attempt was made to lay out two substations so that they could be operated only when the trains might demand the power. At that time automatic operation had not been suggested. The idea was merely to save substation apparatus, in order that the machines might have time to cool down, having planned to over-load them very heavily as the trains went by. The automatic control of such substations, considering the machine capacities there involved, is a little startling, particularly when one has been brought up with the old-fashioned machinery that required the very best of attention.

I cannot agree with the previous speaker, that substations should be placed in certain locations merely for the purpose of preventing electrolysis. There must be some deeper and more general reason than that. Electrolysis where it exists, or where the potentials producing electrolysis exist in a dangerous degree, can be taken care of much more easily, as has been found in one case in particular, by the introduction of a booster set automatically controlled by a voltage regulator. One such installation in Oakland, Cal., is now working out very nicely. The action is entirely automatic and the potentials of the track at the dangerous point are kept very closely to busbar potential, *i.e.*, within a fraction of a volt (on a 1200-volt line), which seems to be quite close enough.

On long inter-urban lines, such as are common in this part of the country, a very great field for this sort of thing seems to be open. One company is now planning a considerable extension on a 1500-volt system, and if such a development as is outlined in this paper can be introduced generally, the facts should be made known.

R. F. Schuchardt: The foundations for economical power generation have now been well laid and the further work of the operating engineer is directed toward refinements in methods and apparatus that will result in still further reducing the cost of that part of the service represented by the electricity.

The installation described in this paper is a very interesting one and is working quite satisfactorily.

As Mr. Babcock has indicated, this development will undoubtedly have an important bearing on the electrification of steam railways.

The authors have stated in their paper and Mr. Place has repeated that while the installation described is used in connection with railway service, the scheme is also applicable to lighting systems. This is true, but to a very much lesser extent. The conditions surrounding an interurban railway system, such

as the one referred to in the paper, are unusually favorable for the development of automatic substations; but with a lighting system, especially in the larger cities, the problem is not so fortunate with regard to simplicity. In the latter the voltages must be maintained much more closely; the inter-connected network maintains the voltage so that if a machine drops off there is a comparatively small decrease of pressure in the back feed; and the regulating devices also complicate somewhat, the starting arrangement. While these and other conditions make the situation somewhat complex, the engineering solution is of course, not difficult but it is probable that the cost of the necessary apparatus for making such lighting substations automatic without sacrificing reliability may be so high that the fixed charges on this apparatus will much more than offset the difference in the operating cost.

Another element that enters is the size of unit which can be safely operated in this manner. I do not believe that the authors would at this time recommend placing a 3500- or 4000-kw. unit on the automatic basis and the cost of available space, especially in the larger cities, is so high that units of such size must be used to obtain an installation which is sufficiently economical to permit selling energy at the low rates prevailing in such cities. In such lighting substations, however, where units are comparatively small, as in outlying substations, the problem may be successfully worked out. Since, as stated in the beginning, the successful solution will result in further economy, it is desirable that central stations assist in this development and I would suggest that several companies try out this scheme, say, on a single unit in one of the smaller substations where it will be under the eye of an operator who is taking care of the other units in the same substation. Such actual trials should assist materially in discovering faults which may be in the present apparatus and in eliminating them.

H. R. Summerhayes: In my connection with the engineering department of a manufacturing company I have noticed the wide variety of requirement of automatic stations. The first station, which at that time was called an automatic station, was that installed in Detroit—it is really a semi-automatic substation, controlled from a distance. The starting was taken care of from a distance, but the operation of the station was automatic, so far as taking care of short-circuits or other emergencies.

Since I worked out the details of that station, which was originally suggested by Mr. Dow, of the Detroit Edison Company, I have been consulted a good many times on other automatic stations, and as I say, I have noticed a very wide variety of requirements. All the operators appear to have different requirements—some prefer to start with a time-clock, and some prefer to start according to the demand for current, as is the case with the substations described in the paper now

under consideration. Other operators believe that for railway substations the tendency is toward controlling a number of small substations from a central station by control wires.

For railway substations the first one in operation, described in the paper by Messrs. Allen and Taylor, uses the principle of inserting a resistance instead of opening the circuit breaker. Other stations have been designed and will shortly be put into operation, in which the automatic operation follows very closely the usual practise of the operator; that is to say, we all know in railway work, that when an over-load occurs and the circuit breaker opens, the operator replaces it, and if it comes out again, he replaces it after an interval, etc. Stations have been worked out in which that is done automatically, instead of inserting resistance, and some engineers believe that this method has advantages over that described in the paper. Other stations have been designed in which a combination of the two methods is used.

In working up the design of wiring diagrams for these automatic substations it is necessary to be familiar with the conditions of operation and to try to foresee anything that may happen. For instance, you have to assume a short-circuit out on the line, close to the station, in the station itself or in the machine, and figure out what is going to happen; and if the apparatus does not take care of it, it should be made to. You have to assume that any relay or any switch may fail, and then you must be able to predict what will happen. The arrangement should be such that any single piece of apparatus in the automatic operation may fail without doing any damage, and that the worst thing it could do would be to shut down the station. Of course, we do not want to do that if we can help it.

The use of automatic substations does away with some operators, there will be a smaller number of operators on the system; but where there are a number of substations there will be required probably one or two inspectors, men more expert than operators, possibly, receiving higher wages. These men would visit the stations and see that they are kept in good shape, so that the expense of operators is not altogether done away with, but is greatly reduced. Heating of the automatic station is not necessary. That is quite an expense in a cold climate. The relays and automatic switches, etc., must be absolutely reliable. They must be reliable in low temperatures if there is no heating in the station. They must be capable of frequent operation. Sometimes widely fluctuating conditions demand quite frequent starting and stopping.

These stations have been designed for either motor-generators or synchronous converters. The details of the starting are somewhat different.

I agree with Mr. Place that there is a future for some of the principles used in these automatic stations, and for the application of some of these principles to the starting of large machines in

city systems. By using semi-automatic starting, we will get absolutely correct sequence of operation and starting, the same every time, eliminating, to some extent, the human element.

I do not believe in increasing the number of sub-stations. That was pointed out in the paper as a possible consequence of the use of automatic stations. I believe it would be better to keep the number as low as possible, even at some increased capital expense.

C. W. Place: Mr. Babcock mentioned the matter of the expense of such equipment. If the saving of a $60 a month operator, and the price of power, say, at 5 mills, is capitalized there is about six or eight times the investment available.

As to the location of substations, my remarks about electrolysis were incidental merely to the fact of locating railway substations in the congested downtown districts, where the return would be short and consequently the drop would be considerably less.

As to Mr. Schuchardt's remarks, the operation of a station at Union, Illinois, has been exceedingly satisfactory. At the time I inspected the operation the commutator of the converter was becoming much better than it had been under hand operation. At that time the station had been in operation three weeks, and where the circuit breakers had been previously opening about twenty times a day, due to overload, there had been two openings of the circuit breaker which had been left in series with the station. The limiting resistance functioned several times while I was in the station and dropped the trolley voltage slightly. In one case the station accelerated a car from directly in front of the station. It worked to perfection.

Concerning Mr. Summerhayes's comments ont he current-limiting resistance versus the frequent opening of feeder circuit breakers, I believe that is touched on in the paper by pointing out the effect of throwing the 600-volt line directly on the railway equipment, working at low counter e.m.f. This easing on of the synchronous converter set of our contol system will be a great advantage and of benefit to the life and condition of the commutators of railway equipment.

Regarding the possible failure of parts, the equipment that has been used in the stations which have been installed has been of standard parts, such as are used in steel mill and switchboard work. They have all had very severe tests and there has been absolutely no failure on that score.

DISCUSSION ON "STANDARD MARINE ELECTRICAL INSTALLATIONS" (HORNOR), SAN FRANCISCO, CAL., SEPT. 16, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915).

(Subject to final revision for the Transactions.)

S. H. Blake: Historically this paper does not go back to the time when the standard navy voltages were based on the use of searchlights at 80 volts. This was somewhere in the period up to 1904, at which time the navy voltage standard was increased to 110-125 volts in order that standard commercial lamps could be used. Since then 240 volts and higher are also employed.

The grounded or one-wire system has never been encouraged in American navy or marine practise.

The Fire Underwriters' Code is usually complied with, in cases where the percentage of combustible material present is such as to warrant special protection against fire.

Wooden molding has been used almost universally for enclosing all conductors on shipboard because it is not affected by ordinary changes in temperature, and also because of its flexibility, but it is being abandoned in recent years owing to the fact that it increases the percentage of combustible material on shipboard. Unlined iron conduit has been substituted, and more recently metal armored cable is being used with satisfactory results.

Internal telephones, signals or alarm systems are, I believe, still fed by the step-down rotary transformer with primary of the standard lighting voltage 110-125 volts, and secondaries arranged for about 20-13.3-6.6 volts, depending on the nature of the signal devices connected in the secondary or low voltage side of the transformer.

Generators and motors used for navy and marine service have also passed through many stages of development, but owing to the growing demand for reliability, under all conditions, standard machines are becoming recognized as possessing the essential qualities required for marine service, and therefore, are for economical reasons used where possible.

Mr. Hornor has touched on the successful use of electricity for ship propulsion. This development will undoubtedly revolutionize much of the established practise of voltage and other features in the application of power on shipboard.

John H. Finney: I want you to consider the important part electricity is playing in modern battleships. When we consider a modern type 30,000-ton battleship, and install some 37,000 horse power, it is a pretty respectable central station plant; and it is unique in the variety of voltages employed. We find, as Mr. Hornor shows, that it uses alternating current at 2300 volts, and direct current at 240, 120, and even at the low potential of 20 volts. Such a vessel, controlled in almost every function by electrical energy in some form, could not be operated without the trained electrical man at almost every point.

DISCUSSION ON "RECENT IMPROVEMENTS IN ELECTRIC LIGHTING OF STEAM RAILROAD CARS" (LANPHIER), SAN FRANCISCO, CAL., SEPT. 16, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915).

(Subject to final revision for the Transactions)

George R. Murphy: For a number of years the ampere-hour meter has been used with satisfactory results as an automatic means for interrupting the charging circuit of a battery at the end of charge. Allowance for the necessary amount of overcharge has been made either by adjusting the meter to run proportionately slower during charge than during discharge, or in some case by manually setting the pointer of the instrument ahead by some pre-determined amount just before the beginning of charge.

Where this method of control has been applied to situations involving daily cycles of battery charge and discharge of considerable amount and exhibiting some degree of regularity, as in electric vehicle service, the results obtained have been generally satisfactory.

The operation of a battery in train lighting service in combination with an axle-driven dynamo is, however, of a very different character. The amount of discharge required under normal conditions is usually comparatively small, but there is no degree of uniformity; the work falling on the battery may be light one day and heavy the next as traffic conditions change and cars are shifted from one run to another.

The application of the ampere-hour meter to train lighting as described by Mr. Lanphier has undoubtedly produced very beneficial results from the standpoint of battery operation in connection with existing axle lighting equipments and constitutes an important advance toward ideal conditions. It must be borne in mind, however, that battery control by means of the ampere-hour meter is based on giving the battery a predetermined percentage of overcharge in ampere-hours; that is, the number of ampere-hours put into the battery during charge is equal to that taken out on previous discharge plus a fixed percentage. This method of operation is not theoretically correct, and in practise is approximately so only under certain conditions.

The necessity for overcharge of a battery is due principally to two causes. First, the current put into a cell during charge is not all effective in producing the desired chemical reactions in the active material. Some of it is wasted in decomposing the electrolyte, as evidenced by gasing. The amount of this waste varies as the charge progresses, being quite appreciable toward the end and almost negligible at the beginning, if the charging rate is held constant. It also varies with the rate of charge, cell temperature, type and age of the plates, etc.

The second cause for the need of overcharge lies in local chemical action in the cell, which takes place more or less at

all times, but varies also with temperature, state of charge, acid density, etc. This latter effect is almost if not quite independent of the amount of work a battery does, but is more nearly a function of time. In the case of a heavily worked battery it may be almost negligible in amount as compared with the first cause, but where a battery is lightly worked, as is generally the case in axle lighting service, the over-charge required is found to bear no predetermined relation to the amount of discharge, but is more nearly a function of time.

To meet these conditions the constant voltage system of control has been introduced for axle-lighting and has now been in commercial service for nearly three years, long enough to establish the fact that the operating results are practically ideal. In this system the voltage of the axle-driven dynamo is held substantially constant for all speeds above the "cut in" speed and under all conditions of load and battery state of charge. This constant voltage is fixed at a value equal to about 2.2 to 2.25 volts per cell, which, for 16 cells, is 35 to 36 volts. It is found that at this voltage an empty battery is rapidly recharged at a comparatively high rate of charge, tapering off as the battery becomes full in such a manner as to keep just below the gasing point. This method of control is ideally automatic, as it takes care of all the widely varying conditions obtaining in train lighting service. During the winter, when local action is at a minimum, the amount of overcharge is less, while during the summer the amount of overcharge is automatically increased, without change of adjustment, to compensate for increased internal losses at higher temperatures. If the car stands idle for a few weeks, and the battery becomes partly discharged, it is immediately recharged when service is resumed. After the battery has been discharging for a few minutes, during a station stop, and the dynamo is then brought up to speed, the charging rate is at first comparatively high for a few minutes until the amount taken out of the battery has been restored, when the rate tapers to a small trickling charge. The fixed voltage of about 2.2 per cell is so low, that no harm will result if the battery is subjected to it indefinitely.

Experience with over 60 of these equipments in all parts of the country, in express and local service, summer and winter, and with different lamp loads, has shown that the battery requires no charging other than what it receives in regular service and that it is at no time charged excessively.

Investigation will doubtless show that as the conditions secured by the ampere-hour meter control approximate a constant voltage across the battery terminals, the results become more nearly ideal. It will be noted that in the arrangement described by Mr. Lanphier, when the pointer of the ampere-hour meter has been brought back to zero, indicating a fully charged battery, the voltage is reduced not to the true floating point, which would be 33.6 volts for 16 cells, but to between

34 and 35 volts. This increase above the floating point is sufficient to permit a small trickling charge to flow into the cells continuously. Experience with the ampere-hour meter control points to the necessity for still further increasing this so-called floating voltage and it is believed that when an adjustment is secured which is suitable for all the varying conditions of car lighting service, the apparatus equipped with ampere-hour meter control will in fact be operating under constant voltage control a large percentage of the time, and the difference in results obtained by the two systems during the balance of the time will be negligible.

It may be interesting to note that the constant voltage system referred to above employs the reaction type of dynamo invented by Rosenberg, and the field control to secure constant voltage is obtained by means of a Wheatstone bridge connected across the dynamo terminals containing fixed resistances in two opposite branches and iron wire ballasts of high temperature coefficient in the other two branches, the field being connected across the free diagonal of the bridge.

DISCUSSION ON "THE EFFECTS OF TRANSIENT VOLTAGES ON DIELECTRICS" (PEEK), SAN FRANCISCO, CAL., SEPT. 16, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915).

(Subject to final revision for the Transactions)

J. C. Clark: Prof. Harris J. Ryan has recently performed an experiment which, in a qualitative way, strikingly illustrates the principle of the energy time lag brought out in this recent work of Mr. Peek's. Referring to Fig. 1, *H* is a large helix carrying 8-10 amperes at a frequency of 90,000 cycles per second. The oscillatory circuit *LC* is mounted so that its inductance *L* is coupled inductively with *H*, and a needle gap *G* is connected across the circuit *LC*. *C* is a moving plate condenser capable of smooth adjustment, so that, by turning it to a proper position, the circuit *LC* will be tuned to the frequency of *H*.

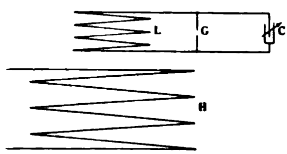

FIG. 1

It is found that when *C* is turned by hand moderately fast from one end of its range to the other, no discharge whatever will take place at *G*; but that, by moving *C* quite slowly through its range, *G* will discharge at the position of *C* corresponding to tuning for circuit *LC*.

E. E. F. Creighton: We have all of us known for a long time of the dielectric spark lag, and in some few cases we have had fairly definite ideas of its value. All those who have operated transmission lines have seen lightning discharges go by a gap, into the apparatus and cause harm. In a great many of these cases the trouble has been due to the dielectric spark lag. If it were a single impulse in the lightning stroke one could be quite sure the fault was dielectric spark lag. If on the other hand there was a wave train, then there is another phenomenon entering, not only the spark lag of the gap, but also the possibility of the wave train forming a resonance internally in the apparatus and thereby causing a localizing of the energy of the surge. The wave train may consist of a dozen gradually decreasing cycles, and may pass by the lightning arrester gap without sparking over it. But when all these dozen cycles are concentrated in local oscillation in a coil of the apparatus, either transformer or generator, then the voltage will rise to very much greater value.

In vacuum lightning arrester work we have had many illustrations of one of the factors brought out here by Mr. Peek, namely, the initial ionization. The vacuum lightning arrester requires a voltage of from 280 volts to anything higher, usually not above 600 volts, to cause this spark to pass. We have had great trouble in comparing one arrester with another, on account of the variations in spark voltage. We finally came to the conclusion, borne out by a great many experiments, that the difference in spark voltage was due, not to the formation of corona or anything of that kind, but simply to the fact that

there was not an ion in the field. We would have sometimes to wait from two to even fifteen or twenty seconds for one of these little ions to float around into the gap, and get the impulse from the potential and strike an adjacent molecule and thereby break up more ions, and in that way reach the condition of saturation.

Percy H. Thomas: It is interesting to observe that the spark-over voltage on the insulators at very high frequency seems to be about the same for wet anddry conditions. Do I understand that correctly?

F. W. Peek, Jr.: Yes.

Percy H. Thomas: That has a pretty practical bearing on transmission line work, because the breakdown voltage or the flash-over voltage of the line insulator is determined, not so much with regard to the line voltage, as to lightning or transient voltages. So if under those conditions, the moist condition does not lessen the discharge voltage, that will be a fact to bear in mind in making a judgment on the relative value of different line insulators.

The first question that occurs to your mind in looking at these results from a scientific point of view, is always that question as to what the voltage, *at the spark gap or on the actual material between the terminals,* as distinguished from the total generated voltage, is during these very high frequencies. If I understand Mr. Peek's experiments correctly, this is determined primarily by calculation. Is that correct, Mr. Peek?

F. W. Peek, Jr.: Yes. The calculated voltages, however, agree with sphere gap measurements.

Percy H. Thomas: I understand that you calculate the natural frequency of the oscillating circuit and take into account the resistance, inductance and capacitance, and thus get the wave front, and from these you get at the voltage. You recognize certain errors of one-half per cent, no doubt due to lack of knowledge of the exact constants. Do you consider the skin effect in the conductors? That presumably is negligible.

Is it possible to make measurement of this potential by placing some suitable device in the electrostatic field, be tween the discharge points, or at some other convenient points, and get a direct measure of the field intensity? This would be getting at the voltage from the other end, but would eliminate many of the possible errors of the calculation method.

Considering the subject more broadly, it is apparently possible to ionize air at enormously high frequencies. Ionization by lightning and ionization by X-rays represents the separation of electrons from molecules or atoms by an *alternating* electromagnetic force, which has a frequency many thousands of times as great as any employed in these experiments. Why should not the time lag discussed in this paper have a very serious effect and prevent all ionization? Perhaps it does have an important part.

The production of frequencies higher than one million cycles per second requires a pretty small physical circuit, at least such frequencies are ordinarily produced through a small physical circuit, and I ask Mr. Peek if he will give an idea, offhand, as to about how large in feet or meters, or inches, the apparatus he used was, so as to give us an idea whether in actual service, in a large transmission line, there is a possibility of getting frequencies higher than one million cycles per second, and whether the presence of the line conductors and other things would limit the possible high frequencies, and also whether there would be energy enough to be serious.

One more question. Is it not possible to calculate the potential energy introduced into a given volume of air when a certain amount of ionization is produced? If that can be calculated it would be interesting to check one of these needle point gaps and take into consideration the amount of air which may be affected by the discharge, and see how much energy it would take, and compare that with the energy which flows through the circuit in a millionth part of a second, or whatever time is used, to see if these are of the same order of magnitude.

There is one other factor which perhaps ought to be spoken of in connection with the effect of a very high frequency in its relation to the amount of energy that can be supplied to the air gap, and that is this: Very few types of apparatus other than sphere gaps and perhaps needle gaps are so arranged that the voltage will always be distributed in the same manner between the terminals; take, for example, a suspension insulator, which has petticoats, the opposite sides of the petticoat constitute a certain amount of capacity, and the surface has an uncertain amount of leakage resistance. The distribution of potential over the insulators will therefore be different, according to how rapidly voltage is applied. If you apply a d-c. voltage and leave it on the insulator for some time, there is a certain distribution of voltage, certain parts will have one potential, relative to the terminal, and certain other parts will have another potential. If, however, you put a very rapidly changing voltage upon the same insulator, the different parts may not have the same relative voltage, so that there will be a greater or a less tendency to break down locally, which may mean, break-down over the whole insulator.

It seems to me this change of the distribution of potential over the insulator, is a thing which must confuse any effect of the measure of time lag, strictly considered.

In considering the protective power of the sphere gap or a needle-point on neighboring insulation, Mr. Peek has said that in the case of the needle-point gap, it requires twice as high a voltage to break down at the high frequency, as at ordinary frequency, and that it therefore does not have the proper protective power. This he explains by the statement that it takes energy to break down the needle-point gap, but it requires

more than that fact alone to explain it. The needle-point gap must not only require energy to break it down, but it must have the capacity to refuse to take the break-down energy at a high frequency. The mere fact that the gap did not spark across would not necessarily prevent its protecting solid insulation, provided the gap could receive sufficient current to relieve the pressure. Do I make that point clear? It is not sufficient that the needle-point gap shall require energy to break it down, to explain its failure to protect solid insulation, it must also have the power of choking back and deflecting the energy coming from the exciting source into the solid material to cause the failure to protect. Will Mr. Peek give more information on that point.

R. W. Sorensen: There now appears to be a general recognition of the theory of ionization by collision as first advanced by Professor Harris J. Ryan in his paper, "Corona in Air and Oil" given some four or five years ago.

This step, coupled with the definite establishment of the value of the sphere gap as a measure of voltages of practically all frequencies, will do much toward the standardization of a common language for the communication of ideas relative to this class of phenomena.

Speaking of this matter of a common language for the communication of our ideas relative to a subject, let us consider the term, "ionic saturation," as used by Mr. Peek in this paper. It seems to me that this may lead to confusion in explaining to students for the first time just what takes place, because I do not see how it can have the meaning of full as when applied to such uses as a saturated solution or magnetic saturation. That is, I do not see how we could say ionic saturation any more than we might say that a ball thrown up against a wall with sufficient force to cause it to break, can be said to be saturated with force or energy, because there was enough to destroy it.

As a better expression for this phenomena I would suggest possibly the expression, culmination point, meaning the point where sufficient ionization has taken place for breakdowns to occur, rather than that no more ionization can take place in the path of current flow.

Considering the destruction of solid insulating materials, is it not possible that the cumulative effect of over-voltages is due to the destruction of parts of the insulation near the point of ionization by heating at the point where the corona streamers are attached to the material under stress? For example, I have seen fibrous materials, porcelain, and glass, tested between electrodes to which was applied high frequency voltages, glow at the points of contact of the electrodes and the materials under test for a period, and then break down in such a way as to show that there was heat developed before the arc through the insulating material took place. Also in working with a

resonator or Tesla coil, I have noted that if the discharge is allowed to jump directly to the body it burns the flesh, thus destroying it at the point of contact.

In a porcelain insulator, of course, the amount of material destroyed by this heat would be insignificant, but the intense local heat would undoubtedly set up strains, causing cracks to form, these cracks constituting a weakened place, made more and more so at each wave front, which must be withstood at that point.

Such a supposition will be entirely in accord with time voltage relation necessary for break down of insulators, because the greater the energy the more quickly is the heat generated at a point and the greater the stress on the material, because of the difficulty of getting this heat conducted away from the point of application.

I take it that the curve for air and also for insulating materials, showing the relation between voltage and time, cannot fall below the critical voltage of the material, even for infinite time.

F. F. Brand: Mr. Peek's paper has brought out and explained many phenomena of break down, which until quite recently were almost unexplainable. The time and energy theory explains to us why insulation having a deeply corrugated surface on which breakdown by flashover must occur by successive building up of corona over a long surface takes a long time or a high transient voltage to flash over, due to the large energy required to form the corona, and thus does not flash over so readily under transient voltages.

It is also interesting, and indeed fortunate, for us, that the spark lag time for these corrugated surfaces increases with decreasing air pressure, and is not appreciably affected by dirt and moisture. The flash-over of insulators at high altitude by transient voltage is not so likely to occur as would be imagined, due to the large time lag at lower air pressure, and due also to the fact that corona will occur readily on the line wires and absorb energy from the transient.

The large number of failures by puncture of porcelain insulators in service is undoubtedly due to progressive breakdown caused by transient voltages which are cumulative until complete puncture occurs. This also shows why insulators immersed in oil which are absorbent of oil, such as paper, pressboard, etc., give such enormously high resistance to puncture by transient voltage, as not only is the time lag of the solid high, but this absorbed insulation is not greatly subject to breakdown by a cumulative process, as it is to a greater extent self-healing by the oil.

F. W. Peek, Jr.: The wet and dry spark-over voltages for impulses of short duration are generally very nearly equal; rain has less effect on the impulse spark-over voltage than on the 60-cycle spark-over voltage. This matter is being further investigated.

Percy H. Thomas: Can you tell me offhand where it becomes evident? How about 50 kilo-cycles?

F. W. Peek, Jr.: The shorter the duration of the impulse the more nearly the wet and dry spark-over voltages correspond. For example, referring to Table XIII, Insulator A: The wet 60-cycle spark-over voltage is 65 per cent of the dry spark-over voltage; the wet spark-over voltage for a single half cycle of a 100-kilocycle wave is 97 per cent of the dry impulse spark-over voltage; the wet spark-over voltage for a single half cycle of a 500-kilocycle wave is 98 per cent of the dry impulse spark-over voltage. It should also be noted that the wet impulse spark-over voltage is in both cases higher than the dry 60-cycle spark-over voltage. The gain in wet and dry spark-over is less and less as the duration of the impulse increases; it is, however, quite appreciable for a single half cycle of a 50-kilocycle wave. For very low-frequency surges the 60-cycle condition may be approximated. This, naturally, has a very important practical bearing. We are at present investigating the *wet* 60-cycle and impulse spark-over voltages at high altitude. It must be kept in mind, in this particular discussion, that impulses are referred to and not continuously applied high frequency. (See Tables XVI and XVIII for comparison). Continuously applied high frequency causes break-downs in solid insulations at very low voltages, produces large corona losses, etc. The effect of each half cycle is cumulative.

Percy H. Thomas: The wet and dry would be practically the same?

F. W. Peek, Jr.: The wet and dry spark-over voltages for the 50-kilocycle impulse are probably very nearly equal, for many designs.

Percy H. Thomas: Is it when the resistance of the water gets high enough that it checks back?

F. W. Peek, Jr.: The shorter the duration of the impulse the more nearly the spark-over voltage is independent of the resistance of the water.

Percy H. Thomas: With perfectly pure water, then, with 50-kilocycles you get very much the same effect, wet and dry?

F. W. Peek, Jr.: Yes. The water used in the tests under discussion varied in resistance between 2,000 and 7,000 ohms per cm. cube.

Mr. Thomas has asked in regard to the method of determining the impulse voltage and also in regard to the space occupied by the apparatus. The impulse voltages are calculated. The method of making the calculation is fully explained in the paper. The impulse voltage is produced by charging a condenser to a known voltage and discharging it through an inductance and resistance. The transient current produces a transient or impulse voltage drop across the resistance which is readily calculated from the constants of the circuit. The condensers were built up of glass plates; the induct-

ances were single layer coils; the resistances were straight water tubes. The constants of all of these were readily measured or calculated. The floor space occupied by this test was about 10 by 12 ft. The constants of the circuit will be found in the paper.

Percy H. Thomas: About how many turns have the coils?

F. W. Peek, Jr.: That depends on the frequency, wave shape, etc.

Percy H. Thomas: Per million cycles?

F. W. Peek, Jr.: About 20 turns. There are naturally, a greater number of turns for the lower frequencies. I might state that the possible sources of error were investigated. The arc resistance at A, Fig. 1 of the paper, was investigated and found to be small. Voltage was also measured across sections of the water tube resistance R_1, and found to check when compared to the voltage across the whole tube. The skin effect in R_1 was also not measurable. The probable error should generally not be greater than about 2 per cent, which is very small when the nature of the test is considered. The chances of error increase with increasing steepness of wave front.

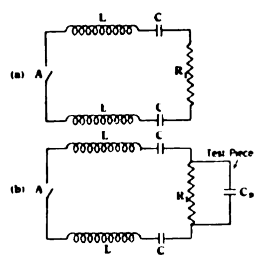

FIG. 2

There is one source of error which was guarded against, but which should be mentioned, the effect of the capacity of the test piece on the wave shape. The wave is calculated for circuit 1*a*, See Fig. 2. The test piece is placed across R_1 and is equivalent to adding a capacity across R_1. The solution of 1 (a) involves a quadratic, of 1 (b) a cubic and is quite tedious. The general effect of C_p is always to delay the time of maximum of the wave, and to increase the value of the maximum with increasing capacity up to a critical value of C_p; the maximum then becomes less and less with increasing C_p and finally falls below the maximum for $C_p = 0$. In this investigation the value of C_p was never allowed to become great enough to appreciably affect the wave shape.

The calculated impulse voltage and the impulse voltages as measured by spheres, using the standard 60-cycle curve, always checked within a small per cent.

Percy H. Thomas: Was the sphere gap curve calculated at 60 cycles?

F. W. Peek, Jr.: The standard sphere-gap curve is a curve measured at 60 cycles. We have also given a formula for calculating it.[1] The curve does not vary for the same maximum of voltage at 60 cycles, 25 cycles or direct-current.

Mr. Sorensen has asked during his remarks, if break-down will occur at any voltage if the time is long enough. No, it will not. There is a certain minimum voltage at which break-

1. See "Dielectric Phenomena in High Voltage Engineering", Chap IV.

down will occur in infinite time. This will be made more clear by a brief discussion of the probable mechanism of break-down which I will now give. This discussion will also answer questions by Messrs. Creighton and Thomas on the effect of initial ionization.[2]

In air there are always a certain number of free ions. The number will vary, and may be greatly increased in the vicinity of any electrodes by means of X-rays, ultra violet light, etc. When potential is applied to the electrodes, the negative ions, or electrons, are attracted toward the positive electrode. The velocity at which free ions move at any point depends upon the field intensity or voltage gradient at that point. When the voltage gradient anywhere reaches 30 kv. per cm. the velocity of the ions become sufficiently great in their mean free path to produce new ions by collision with atoms or molecules by separating them into positive and negative parts. If the process continues ionic saturation may result after many successive collisions. Ionic saturation is corona or spark. A finite thickness of air, however, must be subjected to 30 kv. per cm. or over, in order that spark may result. Whether ionic saturation, and therefore spark or corona, will take place at a given point will depend upon whether ions are produced at a greater rate than recombination, escapement to other parts of the field, etc., this in turn will depend upon the regularity of the field, electrode spacing, etc.

Breakdown or corona cannot begin to form until the voltage is high enough to produce somewhere a gradient of 30 kv. per cm. for the electrodes under consideration. The voltage at which ionization by collision begins, and at which spark-over takes place, will, therefore, be practically independent of the initial ionization, or number of free ions at the start, if the time of application is not limited. The time to reach ionic saturation should vary with the initial ionization.

In the case of an *impulse voltage* of steep wave front *ionization starts* when the continuously applied breakdown voltage is reached; ionic saturation does not occur until the voltage has risen considerably above this value, a short interval of time later. Thus the impulse voltage required to spark-over a given gap is always higher than the continuously applied voltage, the difference depending upon the irregularity of the field, etc. With spheres, where the spacing for a given voltage is small and the field nearly uniform, it is only necessary to ionize to saturation a small short tube of air to cause spark-over. The ions are all along this tube subjected to nearly the same gradient, and all parts break down nearly simultaneously; there is no previous corona formation. The time element is very short. With needles, the spacing for a given voltage is comparatively very large. Local break-down first starts at the

2. See "Dielectric Phenomena in High Voltage Engineering", Chaps. III, IV and VIII.

points in this irregular field; a sphere of corona is gradually formed around each point as the voltage increases; finally, spark-over occurs. There is chance for recombination and escapement; the energy stored in the field must be supplied through the resistance of the gradually forming corona spheres. The time lag of the needle is thus large—an impulse voltage much higher than the 60 cycle voltage is required to cause spark-over. The lag of the starting point of corona is generally very small. This should be so, as the start of corona is spark-over from an electrode to space, generally, in a more or less uniform field. The effect of varying initial ionization on the time lag of spark-over is generally not measurable. This is apparently so because the starting corona, which has a very small lag, supplies greater initial ionization than can generally be supplied by external means. All this is fully treated in the paper. Initial ionization may play an important part at low air density where it may be an appreciable percentage of ionic saturation.

Percy H. Thomas: Have you made experiments on that condition?

F. W. Peek, Jr.: Yes, the effect of initial ionization at low air densities, and under other conditions, is discussed in the paper, as is also the effect at very small spacings where the probability of an ion reaching the space between the electrodes from the outside is small. Mr. Creighton has touched on this in his discussion.

Mr. Thomas has also asked in regard to the effect of the impulse voltage distribution in the insulator under test, and if it does not modify the theory outlined above; The voltage distribution must change greatly after the spark begins to form; I do not believe it changes the general theory of lag outlined above. It must be considered in special cases.

In practise we desire to know the characteristics of different types of insulators. Some insulators spark over more readily than others on transient voltages. For instance, two insulators or bushings of different designs may both have a spark over voltage of 100 kv. at 60 cycles, while for a given impulse the spark-over voltage of one may be 110 kv., the other 200 kv. This investigation has determined the different factors affecting the time lag so that either type may be designed at will.

Two different lightning arrester gaps may have 100-kv. spark over voltage at 60 cycles, the condition which determines the setting on a line, while for a given impulse one may require 200 kv. to spark it over, the other only 102 kv. These different types may also be designed at will. It is obvious that the 102-kv. gap, and the 200-kv. bushing would be desirable in practise. I have in the laboratory two different gaps connected directly in multiple—the 60-cycle setting for one is 100 kv., for the other 200 kv. A spark may be made to pass, as desired, over one gap or the other by changing the steepness of the applied impulse.

Percy H. Thomas: My question was as to the sufficiency of your explanation. When you say that the needle point requires energy to break down, you want to supplement that energy to explain the phenomenon. The real effect is the time, rather than the energy.

F. W. Peek, Jr.: It cannot be said that any gap has a definite time lag for all impulses; it requires time and voltage. If the voltage increases rapidly it will go up to a higher value, but spark-over will occur in less time, so that time and voltage are linked together and are interdependent. It is really a matter of energy.

Percy H. Thomas: That is not the point I had in mind.

F. W. Peek, Jr.: That answers, I think, the point from the protective standpoint and the standpoint of insulator design.

Percy H. Thomas: I understand what you are explaining now. My point was this, that while the phenomenon is clear, the explanation that it is due to the effect of the energy required to break down the needle gap, would not explain why the lag should occur with a needle point and not with a sphere.

F. W. Peek, Jr.: I may make myself clearer by citing a specific example. Set a needle gap and a (25 cm.) sphere gap so that both spark-over at 100 kv. maximum for continuously applied or 60-cycle voltages. It will be found that the spacings are approximately 3.5 cm. for the sphere gap, and 15 cm. for the needle gap. The sphere gap spark-over occurs along a straight tube 3.5 cm. long. As the gradient along the tube is fairly constant, ionization starts all along the tube at about the same applied voltage. There is no previous corona formation or field distortion. It is necessary to bring a very small amount of air up to ionic saturation. With the needle gap the field is intense at the point, and not intense a short distance from the point. As the impulse voltage rises from zero corona first starts to form around the point and gradually extends out as a sphere around the point with increasing voltage. The field is, thus, continuously changed and part of the energy is supplied through the conducting corona which is formed. The rate at which the energy necessary to cause breakdown can be supplied is thus limited. As this comparatively large volume of air is ionized there is also probably recombination, escapement of ions, etc. Spark-over finally results if the voltage continues to a sufficiently high value to produce ionic saturation in the spark-over path. The required energy is much smaller for the sphere and it can be supplied much more rapidly than to the needle. The impulse spark-over voltage for the sphere in this case may be, say 100 kv.; for the needle 200 kv. The rate can be calculated.

Percy H. Thomas: The real criterion to determine when that will break down is when ionic saturation is reached?

F. W. Peek, Jr.: Yes, that is apparently correct. I have given the general laws in a summary at the end of the paper.

J. Murray Weed: I suggest an explanation might be arrived at by considering that the energy must all flow into that space in the air from the points of the needles in the one case, and in the other case it is the whole surface of the sphere which must flow into the space in the gap. It must flow through the air to energize the air further out from the terminal, and in one case it has to flow through a small cross-section of air from the point of the needle, and in the other case has a large surface on the sphere to flow to.

F. W. Peek, Jr.: In the case of the sphere, the energy is really supplied along a small tube connecting the nearest surfaces.

H. C. Stephens: There is one point which seems to be inconsistent with the statement you made some time ago, in which you said it took no appreciable time to accomplish the ionization.

F. W. Peek, Jr.: It naturally must take time to produce ionization; it must take time to supply energy, unless there is infinite power. I stated that the time to produce the initial corona was very small compared to the time to produce the final spark-over in irregular fields. This is so because the start of corona is spark-over, a small distance, from conductor to space over which the field is still fairly uniform.

Mr. Sorensen asked in regard to heating. I do not think that heating need be specially considered in this problem, but rather the tearing apart of the air and the energy supply through the resistance path thus formed to the capacity.

Discussion on "Inventories and Appraisals of Properties" (Cory-Vincent-Norton). San Francisco, Cal., Sept. 16, 1915. (See Proceedings for September, 1915).

(Subject to final revision for the Transactions.)

Overhead Charges

Philander Betts (by letter): In making up the valuation of public service properties, it is customary in many cases to appraise the property by using unit prices which represent the basic cost to the company doing the work and then after the appraisal is completed on this basis, to make additional allowances to cover such items as engineering, interest during construction, taxes, damages and insurance during construction and such other items as are not ordinarily allowed for in making up the unit cost price.

In determining the amount to be added to represent the items referred to, it has been customary to compute these items by adding a percentage on the whole cost, using a single figure to represent the allowance for overhead charges. The amounts allowed or claimed in various cases have ranged from ten to thirty per cent, depending on various circumstances. There has been a tendency on the part of some regulating bodies to hold down these allowances to a minimum figure. There has likewise been a tendency on the part of many corporations to make extravagant claims for these same allowances. Within this wide field, there is ample room for discussion and argument, and such discussion and argument is based in very many cases on assumptions which cannot be easily proven when the entire property of a public utility company is being considered.

It does not require any lengthy discussion to show that the item of interest during construction would have to be paid for a longer period on real estate upon which a building is to be built, than upon the building which is to be built upon it. Interest during construction would be paid for a still shorter period upon the amounts required to install the machinery to be located in the building referred to. In the purchase of real estate, an allowance for brokerage may be necessary, while on the other hand allowances for accidents, damages etc. during the construction period would be entirely out of place in arriving at the cost of the land.

In constructing a complete system for the supply of gas, water or electricity, it is necessary first to make a preliminary study of the territory to be supplied, second, to select in general a location for the generating or pumping station; third, to purchase real estate; and fourth to design a plant suited to the location which has been selected.

The mains first laid, which would ordinarily cover the well built up portion of the town, would be installed in accordance with a general plan, and perhaps by a contractor, while the extensions made at a later time would ordinarily be made as the actual needs for them developed.

Office furniture and supplies and many other items would be put into service immediately upon their receipt, and frequently before the bills for them have been actually paid.

For the reasons given above, it would appear that allowances for overhead charges should be made up for each class of property in order to justify fully the allowances made or claimed.

In the writer's work for the New Jersey Public Utility Commission, it has been customary to gather all possible data concerning unit costs and overhead charges from the books of the company whose property is being appraised. Information so developed shows a wide variation in the actual amounts charged to construction for what are known as overhead charges.

Some companies, in order to justify to themselves the capitalization of all overhead charges including contractor's profits, have entered into contracts with dummy construction companies, and so far as the books show, all construction has been done by the construction company at prices which have included full allowances for all classes of overhead charges.

In a recent case, however, where the financial affairs of a group of companies were being reorganized, it was found, that due to the majority ownership by a very competent engineer who was personally interested in building up for himself a valuable property, that the total amount actually charged for the purposes under discussion was less than 5 per cent, on the cost of physical property. The aggregate value in the group of companies referred to was not far from $9,000,000.

The writer has discussed the subject of overhead charges with the executives of a number of New Jersey public utility companies, and has pondered the subject in order to arrive at a conclusion as to whether overhead charges in the case of appraisal of properties should be included in accordance with the method formerly employed by the company or whether, on the other hand, a fair allowance for overhead charges should not be made in all cases no matter what the conditions under which the company's property was created.

In the very interesting discussion before the Interstate Commerce Commission in the last week in May 1915, at which were present representatives of the railroads and of the state commissions, discussion of overhead charges took place. In following the discussion, it is quite clear that conclusions had already been reached by the majority of those taking part in the discussion, that overhead charges on a fair average basis were to be included in all cases, and there remained only for actual determination the period of time within which the property could be reproduced.

Some three years ago, in an important telephone case before the New Jersey commission, the writer was impressed with the absurdities which have crept into the various definitions of reproduction cost, and which have resulted in casting considerable discredit upon such methods of appraisal. At that time, the writer put forth the following definitions:

Inventory is the listing of all items of material and labor which the particular company was required to produce or provide or obtain in the construction of its plant at the time and in the manner under which it was constructed.

Appraisal is the affixing of such prices to the items found in the inventory as will fairly represent the normal cost considered over a period of years.

At the time of making up an appraisal of this kind, study should also be given to the cost price at the time the work was done, not with a view to placing a different value upon the property existing at the present time, but with a view to determination of the obsolescence or replacement costs which have not been fairly made up by the company from its earnings, and which might now be considered as unearned depreciation, and therefore included as a part of the cost of establishing the business. Failure to make such a study will frequently result in injustice to the owners of the property under consideration.

The conclusion, therefore, must be that overhead charges must be allowed in all cases on a reasonable basis. Their exclusion would result in injustice to a company where high efficiency had been shown in its construction and operation, while on the other hand, inclusion of overhead charges on an extravagant basis, even though paid by the company, would result in injustice to the customers of such a public utility property.

I am therefore giving in a brief way, the detail to be considered in the determination of the proper allowances for overhead charges. The following analysis is based upon classification of accounts prescribed by the New Jersey Public Utility Commission for gas companies, but the principles will apply to any class of public utility property.

ORGANIZATION

It has been customary in many cases to make an allowance for the cost of organization. Under the term, organization, is frequently included many items which, in my opinion, can be best considered in connection with the various classes of property, and I am therefore not making a specific allowance for the organization of the company in addition to the allowances which will be made hereafter in connection with the overhead charges for each class of property, as the expenses of organization, with the exception perhaps of minor allowances for actual legal expenses will be found to be covered in the allowances made hereafter.

LAND

In connection with the purchase of real estate on which to erect a generating plant, there will be preliminary surveys and inspections of property. These inspections and surveys may be made of several properties before a final selection is made.

An allowance for brokerage will ordinarily have to be paid

to the real estate agents concerned in the transaction; the cost of searching the title, conveyancing and recording will have to be borne. For all of these items, I have concluded that an allowance of 5 per cent was proper.

In constructing a gas plant or a set of gas plants, such as are found in the system of a certain large company, it would be reasonable to allow interest on land for a period of two years; at 6 per cent per annum this allowance will amount to 12 per cent. Taxes likewise will have to be paid for two years at 1½ per cent, which is low if anything, a total of 3 per cent.

The total for all allowances for the overhead charges to be applied to land, 20 per cent.

(It is true that in a recent decision of the United States Supreme Court, overhead charges on land were ruled out, it being held that land should be valued at its real present value. The writer is not contending that the land has any greater value because of the overhead charges, referred to above, but insists that these charges must be met, and if not included as a part of the value of the land, must be elsewhere included in order that a proper estimate may be made of the cost of the property.)

GENERAL STRUCTURES. WORKS AND STATION STRUCTURES

Allowances for buildings will include preliminary study made by officials of the company—1 per cent; architect's fee 5 per cent. If in making up the appraisal on the buildings, we use unit costs which represent the cost to the builder, there will have to be made an allowance for errors, omissions and contingencies of 5 per cent; and for accident, fire and tornado insurance during construction 3 per cent, a total of 8 per cent to be added to the actual cost to the builder himself to arrive at the cost to the company, omitting the builder's profit. Inspection during the progress of the work which will be made by the officials of the company has been placed at 1½ per cent, this resulting in an amount which is not far from amounts which are being paid at the present time to engineering inspectors employed by owners. An allowance for interest at 6 per cent for one year also appears to be proper.

The allowance for overhead charges on buildings will therefore be made up as follows:

Basic cost to the builder	100	per cent
Builder's allowance	8	" "
TOTAL	108	" "
Builder's profit, 10.8 per cent on cost to him	10.8	" "
Builder's charge to owner	118.8	" "
Architect's fee and inspection charge 6 per cent on builder's charge of 118.8	7.13	" "
TOTAL	125.93	" "

Interest for one year on amount of money to be expended by company in connection with the building 6 per cent on 125.93	7.55	"	"
Cost of inspection during the progress at 1½ per cent on builder's charge of 118.8 per cent	1.78	"	"
TOTAL	135.26	"	"

I have therefore adopted as the allowance for overhead charges to be made in this case, 35 per cent, which is to be added to the figures representing the basic cost to the builder.

GENERAL EQUIPMENT

General equipment consists of general office equipment, shop equipment, store equipment and stable equipment, and the total value in comparison with the value of the whole plant is small.

Most of this equipment is purchased at or about the time the company actually commences to supply customers, and is of such a general character that it is actually put into service before bills have to be paid. For this reason no great allowance for overhead charges need be made.

Such equipment, however, is somewhat varied in character, and in making an inventory it is liable that many items may be overlooked. For this reason an allowance of 5 per cent is made for errors and omissions. No other allowance appears to be necessary as this equipment is purchased by the operating officials of the company in the regular course of operations.

PLANT MACHINERY AND EQUIPMENT

Plant machinery and equipment includes practically the whole of the manufacturing plant and the following allowances appear to be justified.

The actual allowances in the case of a certain gas company are as set out.

Preliminary study	1	per	cent
Engineer's plans and supervision	5	"	"
Inspection as the work progresses	1	"	"
Errors, omissions and contingencies	3	"	"
Insurance, accident and fire, etc	3	"	"
Interest for 9 months at 6 per cent	4.5	"	"
Fuel and labor in testing the plant	0.5	"	"
Watchman's services	1	"	"
Contractor's profit	10	"	"

The allowance for errors, omissions and contingencies, insurance, and watchman's services must be added to the basic cost to the contractor in order to find the charge made by the contractor to the company.

Taking as the basic cost to the contractor 100 per cent, an allowance of 7 per cent must be first added, making the basic cost to the contractor, 107.0 per cent. To this the contractor

will add a profit of 10 per cent or 10.7 per cent. The total charge which the contractor will make to the owner will therefore be 117.7 per cent. To this must be added the cost of preliminary study 1 per cent. Engineer's plans and supervision, 5 per cent. Inspection as the work progresses, 1 per cent. A total of 7 per cent of the amount charged by the contractor 117.7 per cent amounting to 7.75 per cent. Interest at 4½ per cent for a period of nine months will be paid upon the amount charged by the contractor, 117.7 per cent, amounting to 5.3 per cent. An allowance for fuel and labor in testing the plant at ½ per cent upon the charge made by the contractor amounts to 0.6 per cent. The total of this allowance is as follows:

Charge made by contractor	117.7	per cent
Engineering, inspection and supervision	7.75	" "
Interest during construction	5.3	" "
Testing of plant	0.6	" "
TOTAL OF	131.35	" "

It is probable that the allowance for interest may be too high due to the fact that some payments will be held back until the plant is completed, and to the further fact that contractors frequently accept bonds in payment for work which will afterwards be disposed of in such a way that interest does not commence to accrue until a short time later.

The allowance for fuel and labor in testing the plant and for watchman's services have not been selected arbitrarily, but have been made up by taking a number of typical cases and calculating the actual amounts expended for these purposes and ascertaining the percentage relation between these amounts and the cost of the property.

On the whole, I feel that an allowance of 30 per cent for the overhead charges in connection with plant machinery and equipment is fair.

TRANSMISSION MAINS

Taking as the basic cost 100 per cent, an allowance of 2 per cent for errors and omissions and 1 per cent for casualty insurance appears to be sufficient.

The cost to the contractor will be	103	per cent
The contractor's profit at 10 per cent equals	10.3	" "
Charge by contractor will be	113.3	" "
Interest during construction at 6 per cent for a period of one half year will be	3.399	" "
Taxes at 1 per cent will be	1.133	" "
Engineering 5 per cent on charge made by contractor 113.3 per cent	5.665	" "
Total cost to company by time work is completed	123.497	" "

The allowances made, appear to be so consistent that, I have adopted the figure of 23.5 per cent as the allowance for overhead charges of all kinds on transmission mains.

DISTRIBUTION MAINS

A portion of the distribution mains system will be constructed perhaps by general contractor. In the large systems in existence today, however, the great proportion of the existing systems have been constructed by forces in the permanent employ of the companies, and practically all of the overhead charges have been absorbed and paid through the operating expenses of the company.

In a given case, however, taking again the basic cost as 100 per cent, it appears proper to allow for errors, omissions and contingencies 3 per cent; and for casualty insurance 1 per cent; a total net cost of 104 per cent.

Interest at 6 per cent for six months is 3 per cent, taxes 1 per cent and engineering 2 per cent, gives 6 per cent which must be computed upon the net cost to the company amounting to 6.24 per cent of the basic cost. This gives a total cost to the company by the time the distribution mains are ready for use of 110.24 per cent. An allowance of 10 per cent spread over the entire distribution system appears to be proper.

SERVICES

In the construction of the services to the customers' premises, practically all of this work is done by the company itself, and as stated in connection with distribution mains most of the overhead charges are absorbed and paid for in connection with operating expenses. In the laying of services however, there are frequently obstructions which render estimates somewhat unreliable, and it therefore appears that an allowance for contingencies is necessary. For errors and omissions, I allow 5 per cent upon the total net cost of services.

METERS—METER INSTALLATION—STREET LIGHTING FIXTURES

Practically all of the work under these headings is done by the permanent forces of the operating companies, and it does not appear necessary to make any allowances for overhead charges providing the inventory itself has been accurately prepared.

TOOLS AND APPLIANCES

Tools and appliances by many companies are charged immediately into operating expenses, although the permanent equipment of this kind is naturally properly chargeable to capital account.

Because of the varied nature of such equipment, an allowance for omissions is essential. No other allowance appears to be necessary, and I consider an allowance of 5 per cent sufficient to cover all the overhead charges applicable in connection with tools and appliances.

LABORATORY EQUIPMENT

Laboratory equipment will ordinarily be purchased at about the time the company commences business; will be purchased

by the company's own management; will be installed by the company's own regular forces. In equipment of this kind, however, there is so much incidental work that an allowance should be made for errors and omissions of at least 5 per cent. No other allowance appears to be necessary in connection with this class of property.

In order to carry out the plan laid down above, instructions have been issued to the computers in the employ of the New Jersey Commission somewhat as follows:

The unit prices to be applied in computing the appraised cost of the various classes of property of a certain gas company are to include the allowance for overhead charges in accordance with the schedule for overhead charges given above. There is to be first ascertained the net cost to the one who does the work, be he contractor or company. This net unit cost has been heretofore referred to as the basic cost. To this basic unit cost will be added the allowance for overhead charges in accordance with the percentage heretofore adopted and the unit prices to be used in making up the appraisal will therefore be found throughout the body of the appraisal.

RESULTS OF THE APPLICATION OF ABOVE SYSTEM

Although the allowances for overhead charges range from 5 per cent to 35 per cent, it is interesting to note that in the case of a certain large gas company having four or five plants, and extending over a wide area of country, the net average allowance for overhead charges was 17.2 per cent. I would state further that due to variations in the proportion of plant and property, and to the difference in magnitude of various properties, the application of the above system has resulted in net averages ranging between 15 and 17½ per cent. Below is given a list of the allowances for overhead charges in a number of cases. A perusal of this may be interesting, in comparison with the above statement.

	Per cent
Chicago City Railways, by the Traction Valuation Commission, 1906 (including brokerage)	21.7
Columbus (Ohio) Railway and Light Company (electric) by U. S. Circuit Court, report of Special Master, 1906	9.8
Minnesota R. R. appraisal by Minnesota R. R. & Warehouse Commission, 1908	17.7
Northern Pacific Railway, by Washington R. R. Commission 1908	5.8
Lincoln (Neb.) Gas & Electric Light Company (gas) by U. S. Court, 182 Fed. Rep. 926, 223, U. S. 349, 359, 1909	7.7
Chicago Consolidated Traction Company, by B. J. Arnold and George Weston, 1910	20.4
Puget Sound Electric Railway by Washington R. R. Commission, 1910	15.7
So. Dakota R. R., appraisal by the Board of R. R. Commrs. of South Dakota, 1910	13.7
Consolidated Gas Co. of Long Branch, by the Board of Public Utility Commissioners (N. J.) 1911	12.0

	Per cent
*Kings County Lighting Company (gas) by New York Public Service Comm., 1st Dist., 1911.......	27.1
*Queensboro Gas & Electric Co., by N. Y. Public Service Commission, First District. 1911..........	31.3
Peoples Gas Light & Coke Co., by W.J. Hagenah,1911	17.0
Peoples Gas Light & Coke Co., by Edw. W. Bemis, 1911..	17.0
Union Electric Light & Power Co. (St. Louis) by St. Louis Public Service Commission, 1911........	10.8
Chicago Elevated Railways (City valuation) 1912....	18.0
Consolidated Gas Electric Light & Power Co. of Baltimore, by the Pub. Serv. Comm. of Maryland, 1912..	29.5
The Milwaukee Electric Railway & Light Company, by Wisconsin R. R. Commission, 1912............	12.0
Public Service Gas Company (Passaic Division) by Board of Public Utility Commissioners (N. J.) 1912..	17.6

*Includes an allowance for development of the business.

CONCLUSIONS

Justice to both the company and the customers involves the inclusion of overhead charges on such a basis as would conform to the facts if construction work is efficiently planned and carried out and construction charges are carefully separated from operating charges. Honesty and accuracy in making these separations lead to facts; and to the elimination of assumptions and the consequent danger of having our conclusions discredited. Thus is emphasized the necessity for a carefully worked out program, in accordance with which it is assumed that the property has been constructed, or would be reproduced.

The Value to Operating Companies of Well Planned and Executed Inventories

H. Spoehrer (by letter): Public Service Commission investigation and rate cases in the majority revolve around one question, namely: what is the justifiable rate applicable to the condition appertaining, which will allow a fair return on the investment represented. The justifiable rate being directly dependent on the investment concerned, it cannot be intelligently or fairly fixed without an accurate knowledge of the physical property of the company. This, of course, involves the taking of an inventory, if such is not kept up by the company. Periodic inventories or inventories taken only when necessity demands, are not only more expensive than a running inventory, but in the case of a large property, consume no small amount of time and expense in the making and are usually inaccurate. A running inventory intelligently and carefully attended is then, most desirable on three points, namely expense, accessibility when needed, and accuracy.

Numerous occasions arise where a detailed knowledge of distribution systems, pole lines or other physical properties would be of great advantage to a company. The real need

for information in detail is never fully realized until it is found that it is not available. In all companies, who lay claim to progressiveness and real service, the old system of replacing pole lines, etc. and other property of this kind only when falling down, results in possible accidents, and is not now adhered to; but fixed inventories of these properties are kept up from the date of their installation, and replacements are made when it becomes necessary and before the service is impaired. It is easily seen that a company, whose construction work varies in amount from year to year, is not able to intelligently anticipate the need for replacement, in future years, unless an accurate and complete inventory is kept up of such construction work. To quote a concrete illustration, it is of no value to the owners of a property to know that they have erected poles to the valuation of $400,000.00 unless they know what per cent of these poles will need replacing in the coming year.

It is frequently of material assistance in order to dispose promptly of a company's securities at an advantageous price, if an inventory of its property is immediately available for the inspection and ready for verification of the purchase of the securities.

In the case of smaller properties, which frequently change hands, an available inventory may facilitate, induce and affect a prompt sale.

Operation of a Public Service Corporation involves construction expense to a degree not found in any other class of business. Construction expenditures can be satisfactorily estimated only from previous similar experiences. A well kept inventory is, therefore, an invaluable asset in the fixing of construction estimates.

The question of working out appropriate plans for extensions and replacements is very similar to the one just touched upon. Extensions and replacements can be intelligently estimated as to expense only from figures of previous similar experiences. Where there are no such figures available, plans for extensions and replacements are necessarily less accurate than in the case of similar work having been previously done. Unit costs are made possible only through the keeping of running inventories or similar system, and it is a well known fact that unit costs are an invaluable assistance in planning the expense of extensions and replacements.

Plant and Property Accounts are in a sense inventory accounts. It is a self-evident fact that where no inventory is kept up, the valuation shown on the books of the plant and property accounts can be little depended upon. By means of a running inventory or one periodically taken, corrections can be made of the book values of these accounts, so that these values really represent the physical valuation of the property as they are primarily supposed to do.

In the matter of setting up a proper amount of depreciation

as a reserve for replacement, the data and information gleaned from a running inventory of any property will be inestimable. It will afford actual data as to the life of various classes of equipment, from which an accurate table of rates of depreciation may be compiled.

The municipal ownership agitation and the possibility of properties being taken over by the municipality in some instances, requires a preparedness to refute fallacious statements and also an intimate knowledge of the value of the property.

In submitting bids on city lighting the cost of the service must usually be developed, which involves the valuation of the equipment employed.

Working Capital

Henry Floy (by letter): The term, working capital, is usually taken to include that part of the capital investment of a public utility corporation represented by:

First, necessary cash on hand and in banks, and second, the value of materials, stores and supplies in stock necessary for the normal conduct of the business.

The above limited use of the term working capital does not properly cover and include all of those quick assets which should be recognized and allowed in determining the fair value of working capital required by the ordinary, going utility.

In addition to the elements enumerated above, there should be considered and included accounts receivable and the accounts payable, as well as the value of other assets, such as prepayments, stocks on hand, or possibly even credits, by which the conduct of the business may be facilitated and its cost minimized.

In cases of purchase and sale, the cash on hand or in banks is not ordinarily transferred with title to the property. On the other hand, the present value of stores and supplies, the difference between accounts receivable and accounts payable, accrued interest, wages, taxes and prepayments, are all usually considered and equitably adjusted in the price paid by the purchaser.

In determining the value of a utility, whether for rate making or sale, consideration of all of the elements fairly constituting working capital should be ascertained and included or excluded, as the circumstances may warrant. These elements may fairly be divided as follows:

Current Assets

- Cash,
- Stores and supplies,
- Manufactured product on hand,
- Manufactured product delivered to customers but not billed,
- Accounts receivable,
- Prepayments of insurance, taxes or other normal operating expenses.

Current Liabilities
  Accounts payable
  Interest accrued
  Wages accrued
  Taxes or insurance accrued.

In order that a utility may be enabled to carry on its business with the maximum economy, resulting from advantageous buying and discounting of bills, there must be available, respectively, the highest credit and sufficient cash on hand to take advantage of discounts. It may be argued that it is not necessary to pay for supplies as soon as delivered, because thirty or sixty days credit is obtainable. Again it is claimed, a utility with reasonable credit may borrow from time to time to provide for current needs. The answer to the first argument is that a discount is usually obtainable for prompt payment as the seller must, of necessity, include the interest charge in his selling price, if compelled to carry an account for thirty or sixty or ninety days. In reply to the second argument, borrowing of course requires the paying of interest on loans which results in a higher operating cost to the utility and increases the rates for service rendered, consequently a fairly definite amount of cash on hand must always be held as liquid capital by every properly managed efficient public utility.

To render efficient service a utility must always have on hand and available, an ample quantity of stores and supplies with which to make repairs or replacements that are ordinarily demanded at a fairly uniform rate, but which must be available in sufficient quantity at all times to provide for unexpected or sudden, unusual and exceptional demands. In order to manufacture or provide the commodity, which is later sold to its customers, the utility must purchase and furnish in advance of consumption, sometimes for long periods previous to consumption, such items as fuel, oil, labor etc. Consequently, in addition to cash on hand or in bank, there must be always conveniently available or in storerooms a quantity of stores, supplies, repair and renewal parts, as well as fuel, oil or other raw material, required by the manufacturing processes, that represent a proportion of the capital investment of a properly managed public utility.

In addition to stores and supplies on hand, the value of product manufactured or delivered, but not yet billed, such as gas in a holder or electrical energy delivered to consumers in advance of the monthly billing, may fairly be included. The value of these products, which often represent a substantial part of the capital of a utility tied up and invested in the business, has frequently been overlooked or ignored in fixing the proper basis for rate making. It will be recognized that the books do not show the value of such product as has been manufactured, or possibly sold and delivered, until the bills against the consumers are made out, although the cost of manufacture

has accrued against the company. Where bills are made out at frequent intervals, the value of the product may not run into very large amounts, but where bills are rendered semi-annually, for example, the value of the manufactured and delivered product may prove to be a very considerable portion of the total value of the property.

Under the generally accepted terms and methods of doing business, goods and materials received are not paid for upon delivery, with the result that bills and accounts receivable and bills and accounts payable largely tend to offset one another, but their difference either as a credit or debit must be taken into account in ascertaining the proper and necessary working capital of a utility.

It is frequently the case that the control of a public utility is held by a holding or controlling company through stock ownership. In such cases it is not uncommon practise for the holding company to have turned over to it at frequent intervals, perhaps monthly, practically all revenues received by the subsidiary corporation, then all bills for supplies, equipment, salaries, interest and other large items are paid by the holding company, the subsidiary corporations merely keeping small amounts of cash on hand with which to pay local, current bills. Under these conditions, the holding company and not the local corporations, as a matter of act, requires the bulk of the working capital necessary to conduct the operations of the subsidiary corporations, hence the quick assets and cash on hand of the latter do not indicate the amounts required for the proper conduct of their business, because in such cases, the cash, quick assets and credit of the holding company is used for the benefit of the subsidiary companies. In determining the proper amount of working capital that should be allowed a subsidiary company, controlled in the manner indicated, this credit of the subsidiary company with the holding company is usually equivalent in value to quick assets or cash actually on hand. This arrangement and credit of the subsidiary company with the holding company, together with the cash or other quick assets held locally by the former, the value of the stores and supplies on hand, both locally and at the distributing center, controlled by the holding company and held available for the benefit of the subsidiary company, together constitute the working capital of the subsidiary company. A fair method of ascertaining the total value of the stores and supplies, cash on hand and quick assets that may normally be allowed the subsidiary company, existing under such arrangements and controlled as outlined above, may be measured by the methods suggested as proper for determining the working capital of a utility entirely locally controlled.

It is generally conceded by authorities in Public Service regulation that the question with regard to working capital is not whether any working capital should be provided as a part

of the capital cost, but rather the amount of working capital to be properly allowed in the sum representing the total fair value of the property.

The amount of working capital will vary with the character of the business of the corporation being considered. With street railways, for example, where the fare is paid by the passenger in advance of the service to be rendered, the amount of cash working capital required by such utility will be very much less than in the case of a water works corporation, which sends out bills only once in three or six months and receives a payment from four to eight months after rendition of service.

The cash on hand at any particular period, or the average of different periods, may not fairly indicate the cash quickly available for a utility, because other quick assets or individual credit may permit the drawing down of cash actually on hand to a minimum. In a similar way, the value of stores and supplies found to be on hand at any particular time may not be a fair indication of the amount to be allowed for this purpose. The distance of a particular utility being considered, from the points from which stores and supplies are principally shipped, the time required for filling orders by the manufacturers after placing, the tardiness of transportation, due to distance or congestion, all bear on the question of proper allowance of the quantities and hence the value of stores and supplies.

Various methods have been suggested for determining the proper amount of working capital required for the different classes of utilities under normal or average conditions. A very generally accepted basis of estimate is to base the amount of cash working capital upon a consideration of the annual gross revenues. This basis has been frequently accepted by courts and commissions as reasonable, because related to the amount of business being transacted and dependent, in a large measure, upon those receipts and their usually attendant expenses. Varying percentages of the annual gross revenue have been used for determining cash working capital, varying from 5 per cent to 25 per cent, depending upon the character of the business and the size and credit of the corporation. An examination of the actual cash balances kept on hand by a number of public utilities of different classes, such as gas, electric light and street railway property, averaged over a large number of months, aggregating several years, shows that practically 12½ per cent of gross revenue was maintained as the actual cash working capital on hand. This figure would, therefore, seem to have special weight as showing the normal average condition and the average requirements of such utility.

A second method of determining the normal amount of cash working capital required by a public utility, which is receiving much consideration, is based on an examination of the monthly and annual operating expenses and payments, as well as the conditions under which receipts from the sale of the service

PUBLIC SERVICE COMMISSIONS WORKING CAPITAL ALLOWANCES.

	Revenue	Op. Exps.	Net	Repro. Val.	Working Cap.	Per cent of Rev. Rep.	Val.
WISCONSIN							
Madison G. & E. Co., G.	141,272	82,615	58,657	412,000	(45-50,000)	15%	5.8%
Madison G. & E. Co., E.	199,892	100,293	99,599	535,000	(Suppl. 30,000)		
Beloit W. G. & Elec. Co.	181,661	97,435	83,126		40-45,000 ($\frac{1}{3}$ cash-$\frac{2}{3}$ suppl.)	23.5	
ST. LOUIS COM.							
Union E. L. & Pr. Co. G. / E.				16,976,025	914,948 (484,578 cash)		5.38
MARYLAND COM.							
Consolidated G. E. L. & P. Co. G.					(854,252)		6.9
Consolidated G. E. L. & P. Co. E.				23,433,510	(766,068)		
NEW YORK.							
Bklyn. Boro. G. Co.	224,931	148,365 (including $26,364 amortize.)	77,170	1,136,476	40,000 (half cash and half suppl.)	17.9	3.5
Kings Co. Lt. Co.	642,040	349,792	289,645	2,477,579	80,000 (half cash and half suppl.)	12.5	3.24
Queensboro G. & Elec. Co. G.				1,082,813	30,000		2.77
Queensboro G. & Elec. Co. E.				993,867	45,000		4.55
Rochester Corning Elmira Tr. Co.				7,378,020	100,000		1.36
Buffalo Gen. Elec Co.	1,204,006	681,485	522,521	3,194,159	cash 100,000 M. & S. 51,637	12.6	4.75
Cataract Pr. & Conduit Co.	1,516,100	1,153,000		2,768,785	cash 80,000 M. & S. 40,180	7.95	4.35
Federal Tel. & Telg. Co.	1,057,807	545,419	512,388	2,614,363	cash 60,000 M. & S. 30,000	8.5	3.45
WASHINGTON.							
Pacific Pr. & Lt. Co	653,651	286,718	366,932	4,700,000	255,000 (stores & cash)	40	5.44

COURT DECISIONS WORKING CAPITAL ALLOWANCES.

	Revenue	Op. Expenses	Net	Repro. Val.	Working Cap.	Per cent Rev.-Rep.	
Consolidated Gas Co.	13,552,482	9,936,910	3,615,572	55,612,435	1,616,000 (616,000 Suppl.)	11.9	2.9
Passaic Gas Case				4,750,000	250,000 (cash & Suppl.)		5.7
Third Ave. Railroad	3,164,582	1,704,477	1,460,105	12,179,217	662,118 cash 400,285 Suppl. 261,833	20.9	5.44

rendered by the utility, or received from its customers, by the corporation. It will be seen where receipts do not come in for fifteen days, for example, after the expiration of the period to which such receipts relate, and the bills upon which such receipts are based are rendered the first of the month for service performed during the preceding month, the current liabilities of the corporation being largely incurred before the service is rendered, the payment of which liabilities under the wisest business management should not and cannot be deferred, there must be provided and available sufficient cash working capital to meet at least two months average payments. When bills are not rendered monthly but over longer periods, still larger amounts of cash working capital must be provided than would be indicated by a two months average payment of expenses. Moreover, an amount larger than that required to meet normal average conditions must be allowed to provide for the contingent, unexpected and abnormal condition caused by strikes, financial stringencies, fire, accident or other unusual events, which prevent the normal receipt of revenue or call for more than normal expenditures.

A third basis of ascertaining normal working capital to be allowed any particular corporation is by fixing a ratio of that capital to the appraised value of the property. A consideration of the decisions of public service commissions and courts indicates that the sum of working capital allowed to cover stores and supplies and cash, together with quick assets, varies from 3 to 6 or 7 per cent of the appraised value of the property; the stores and supplies frequently being about twice the amount of cash or cash assets. As explained above, the amount will, of course, vary with the character of the utility being considered and the practise that exists as to the frequency of rendering bills for service rendered and the promptness of payment of the users. From an examination of the decisions of commissions and courts, the accompanying table, showing typical allowances made for working capital, has been prepared.

W. F. Lamme (by letter): To a man of business affairs, it sounds strange to have the statement made as if it were something new, that working capital is necessary, for to him, it is self-evident that such capital must be furnished; however, to the average layman, it seems that the need for such capital must be explained and this is done very completely in the paper by Mr. Norton.

In the appraisal values to be given a public utility, the public or consumers are concerned usually only to the extent of their effect on the rates, and to a minor extent on the effect they bear on the tax rate or additional burden thrown on the general public, but the public utility company, that is its stockholders, is concerned to the extent of conserving its investment and to securing a fair or sometimes more than fair return or dividends upon the same.

Since there can be no public utility without capital and no capital can be secured without assurances of ample returns, then rates must be such as to attract and furnish capital, and after capital has been expended and the rates are fixed by parties or powers outside the control of the utility company, it is manifestly unjust to fix rates which will not yield fair returns on all expenditures made and all risks run.

Such, then, being the law of investment, the chief items in rate making are to find out the amount of the investment—the amount of the risk, and the amount of the returns to be allowed. From these items it ought to be possible to choose a fair rate.

In the above, it is noted that the amount of the investment is the fundamental item, and to illustrate in a concrete form what is meant by this term investment, take the example of the construction and operating of an ocean steamer.

With an ocean steamer, about the following would be the course of procedure.

1. An investigation is made to learn the probability of such a steamer as proposed making a return on a probable cost.
2. What is the probable risk on the cost if made.
3. The approximate cost of steamer.
4. The approximate cost to operate.
5. The probable net earnings.

All the above investigations must cost some person or persons or company something or they would not have been made and are part of the investment and finally if the vessel is built these items of cost must be added to the total other costs and this final amount is what makes up the term which is known as the investment. The owners have a right to a fair return on this investment befitting the risk taken and this should include a reward to the "fellow who had the idea" and carried it to a conclusion.

So in a public utility, which usually starts in a small way and is gradually increased or is absorbed into a larger and more extensive utility, the risk from the start and the returns on that risk should be considered and if the returns are not ample to cover this risk, addition should be permitted to be made to capital or investment in the way of stock or otherwise to compensate in future for risks and losses in the past, and if in the future the earnings have become sufficient to cover this past risk and more, then, the rate should be reduced, but not until then; further, if in the future the early risks disappear then, the property becomes more desirable and the returns can be again reduced to an amount fitting the safe condition of the investment. In other words, the consumer in a public utility, who helps to build up the business should now benefit in the building.

Under the broad division risk should be included the items of superseding and replacing of parts of a plant as

well as replacing of portions of the original investment. There is a tendency in the public mind to reason that the proper basis upon which to fix rates is the cost of the plant new at the time of the fixing of the rates. This is manifestly unfair to the owners, unless an allowance has been made to cover the difference between the original investment and the present estimated new investment. It seems to the writer that this allowance should be made in order finally to give the consumer a rate based on the present cost new, otherwise the public utility commission or other regulating body is almost continually required to meet the contention that a new plant can furnish service for a less rate than that fixed by the regulating body.

Summing up, a public utility must have its investment conserved, otherwise capital is not available for constructing same nor for extending it; any regulation increasing the risk or decreasing the amount of the original investment such as by some method of estimate new strikes at a vital part and is liable to do the public utility harm and finally do harm to the general consuming public.

F. J. Rankin (by letter): In arriving at the total number of days between the average receipt of service and the payment therefor, it does not seem to me proper to include the average days use of total consumption during the month. In ordinary business transactions, payment within thirty days is considered cash, and this rule should apply to the operating company and consumer alike. It is no more right to assume that the consumer's service should be paid for daily and therefore that he should pay interest on his average days use of consumption per month, than it is to assume that the operating expenses should be paid daily, or otherwise draw interest until paid. The average days between the reading of the meter and getting the bills into the hands of the consumer, and the average days elapsed between the delivery of the bill and payment therefor, seem to be proper items to include in arriving at an allowance for working capital. The time due to these two causes, however, should be made as short as possible. This could be accomplished by proper rules and regulations established either by the utility or the commission having jurisdiction. In the illustration given by Mr. Norton, it appears that "discount day" comes fifteen days after bills are rendered, and that the penalty for not paying promptly is very slight, as in this case only seventy per cent of the bills were paid in time to take advantage of the usual discount. It would be to the advantage of consumer and company alike to make the time between the reading of meters and payment as short as possible. The delay from weekly bills is usually such a small item that it is hardly worth considering, and it seems questionable whether or not anything should be allowed on this account, since three-fourths, and probably all, of the consumption during the month

is paid for before the company is required to meet its obligations for the service rendered during the month.

Neither does it seem correct to add the amount due from open accounts to working capital. If bills are not paid when due, they should bear interest until paid. This would place the penalty where it belongs, rather than on the consumer who pays his bills promptly.

It seems that the proper allowance for working capital should include the delay from monthly bills, from the time meters are read until payment is received; merchandise supplies; fuel reserve; and a liberal minimum cash balance.

T. J. Ryan: Mr. Cory has presented general definitions of the various purposes for which valuations have been made, and has outlined the principles upon which each should be based and the factors which should be considered in reaching the conclusions desired. Mr. Vincent has analyzed the organization required and the method of procedure involved in making an inventory and appraisal of a utility's property, with a discussion of the records required to maintain it.

It is a matter of regret that these gentlemen have confined their papers to the generic phases of the subject, and have withheld from us the results of their broad experience and keen judgment in handling some of the specific problems they have met in recent practise, as, notably in the valuation of public utilities the proper application of an undisputed principle is not always clear. This may be illustrated by reference to a recent condemnation suit in which four valuations were presented, with a ratio of 4, 6, 7, and 9, between the values given in the several reports, yet each of the engineers employed will without doubt, maintain most sturdily that he had complied with all the essential principles laid down in the papers we are privileged to discuss.

The points of issue between the reports of engineers that perplex commissions and courts, and which have sometimes resulted in decisions that are the despair of investors, rarely arise from the inventories presented, as it is usually possible to reach a satisfactory agreement even between conflicting interests as to the nature and extent of a property under consideration.

Let us for a moment consider a few extreme instances in which the actual facts are somewhat distorted to make the problem clear, where the effect of the theories suggested may be compared.

First: A certain hydroelectric power plant was installed about twelve years ago. The water wheels and generators, while still operating as efficiently as ever, are of types that are no longer manufactured, making an estimate of reproduction cost or cost to reproduce new, dependent on assumptions that may not be readily admitted. At the time of the installation it was necessary to build a wagon road 32 miles, mostly through rough mountain topography, to a rail point, and haul the

entire equipment over it. Since then a railway has been built to within 500 yards of the plant site. Something over a mile of flume was built of lumber cut from lands adjoining the rights of way, a source of supply which has since been exhausted, and the reproduction of this structure would involve expenditures that would be almost, if not quite, prohibitive.

It is easily conceivable that inventories of this plant made by any number of valuation organizations might be in substantial accord, that their measurements of buildings, dams, canals and foundations would be similar and that their computations of materials required in their construction would not show essential variance, but in the application of values we would expect to find differences of opinion and conflicts in judgment that might well afford engineering skill its highest opportunity in devising a common basis for honest men to meet and work together for a fair and rational conclusion.

Second: A power company built a line extension in which it utilized a quantity of fir timbers that had been assembled to fill a contract for piling but which a rigid interpretation of specifications had caused to be rejected. They made excellent poles and were purchased for 25 cents each. Four years later, when a valuation was made, the sources from which these fir poles had been obtained were exhausted and the nearest available supply was so remote as to make the cost of securing them exceed that of cedar poles of the same length. Considerable decay had occurred at the time of the valuation and about 15 per cent of the poles had been stubbed. In applying the theories of value suggested, we have for comparison:

1. Investment	.25 per pole
2. Original cost	.25 " "
3. Cost to reproduce new	6.00 " "
4. Reproduction cost	4.50 " "
5. Present value (4/10 of life elapsed)	3.60 " "
6. Service value, as measured by cedar pole	5.30 " "

Third: A lumber company built a flume as a means of transporting timber from a mountain forest to markets. After its completion, the company failed to secure sufficient lumber to enable it to go ahead, and the enterprise was changed to an irrigation project. For fifteen years it struggled against adversity and after repeated and persistent efforts was sold for $150,000 cash to new owners. Three years later a municipality endeavored to acquire it as an additional source of water supply, and instituted condemnation proceedings. Numerous valuations were filed, from which the following may be quoted:

1. Investment	$960,000
2. Original cost	1,250,000
3. Cost to reproduce new	718,000
4. Reproduction cost	No estimate
5. Present depreciated value	235 000
6. Service value (as measured by actual sale)	150,000

Fourth: A utility operates a generating plant on a site fronting a navigable stream, which, through the development

of adjacent property and water traffic, became far more valuable for other purposes than that for which it was acquired. An equally favorable site for operative purposes may be obtained at a lower cost only a short distance away, but its use would involve the removal of the plant. With these premises a comparison of theories involves the following:

1. Investment	None-donated
2. Original cost to donors	$ 2,500
3. Cost to reproduce new	90,000
4. Reproduction cost	90,000
5. Present value	90,000
6. Service values (as measured by cost of equally adequate site)	27,500

In the valuation of every large system and to a proportionate degree in every small one, there arises the necessity for fixing the value of structures or equipment that admittedly could not be reproduced within economic limits of cost, and also of giving fair consideration to property acquired wisely doubtless in the light of the time, but which changed conditions and rapidly advancing arts has rendered inadequate or obsolete often far in advance of the termination of its useful life or impairment of efficiency.

Such a valuation regardless of the purpose for which it is made, should be a measurement of the extent and availability of a utility's capacity to serve. It should have for its primary object the determination of the basis on which its owners may, in justice to the public, and with fairness to themselves demand compensation for the service rendered All other purposes and all other theories of value are relatively unimportant, because, when this basis is once fixed, all activities must be adjusted to fit it.

The importance of ascertaining with precision the actual cost of labor and material involved in building a property, or that would be required to replace it, must not be minimized, but they are not a measure of its value.

It is obvious that what in view of later developments may prove to have been an injudicious investment if made in good faith, should be afforded every opportunity to work its way out to stability, but it is equally clear that when this can not be done, there must be a readjustment to a value commensurate with the service the property is able to furnish.

On the other hand, the expenditure of money under intelligent direction in constructing a property designed to meet the present and anticipate the future needs of a community should result in values in excess of cost. It is difficult to believe that managerial ability or capital can be attracted to an industry or an enterprise in which the maximum return is limited by the actual sum invested, and where the hazard of loss is as great as that which has characterized public utility investments in recent times.

An increase of value over cost is not intangible but very real,

as any who have endeavored to purchase a profitable business can readily appreciate.

It may be freely admitted that the process of determining the service value of a utility does not readily lend itself to exact definition, and even that it invites the exploitation of vague theories and opinions based on nothing tangible, but on no other basis can exact justice be accorded by conflicting interests, proper encouragement be given to enterprise, and an adequate reward be afforded those who contrive and create. To follow any theory of original cost, cost to reproduce, or reproduction cost new, rigidly to their logical end, may, and often does result in conclusions so absurdly high in some cases and so low in others as to be equally incompetent as a measure of value.

The valuation of public utility is a means to an end, never the end itself. In almost every case it includes within its scope questions in which the lawyer and accountant are vitally interested, and the rational consideration of the problem depends largely upon their intelligent advice and cooperation in collecting and presenting the data involved.

F. E. Hoar: One thing seems apparent to me, and that is that there is a great confusion of the terms, cost and valuation. It seems entirely illogical to me that the present day prices, for example, should be added to a historical plant, or should be applied to a historical plant, in order to measure value. I feel that such an estimate is entirely illogical, and can result in nothing but further confusion. If present day prices are to be used, I see no way in which a value can be measured, other than to apply those prices to a substitute plant, or to a plant which would reproduce the service at this time. In reproducing the cost of a property, or reproducing the property on the historical method, it would undoubtedly be necessary to use historical prices and the historical plant. I think that this would be perfectly obvious when we consider that it would be physically impossible to reproduce an existing plant that has operated over a considerable number of years, but in reproducing this plant on the historical method, we introduce the question not of value, but rather one of equity, one which is some measure of what the company should be entitled to earn for the money that they have invested. I think that there is no conflict in the opinion of most of us as to equities in the problem, and that a company investing its money reasonably and honestly should be entitled to a fair return upon that money. Of course, engineering estimates must pre-suppose honesty and ordinary business judgment; otherwise, we could use simply the cost obtained from the company's books. Without suggesting that such accounts may contain items, which are not reasonable or honest, I think that, to the engineer at least, he would feel more sure of his position if he estimated the cost to reproduce that property at the time and in the manner in which it was actually

produced, using the prices which obtained at that time. That, to my mind, would indicate what the company should earn on, if we assume in advance that it is entitled to earn interest on each dollar invested. If we assume that the company is entitled not to earn on the investment but rather on the present value of the property, then we must disregard the question of cost entirely, unless it be the cost to reproduce the service. I think, when it comes to questions of value, the basis of calculation is, the cost to reproduce the service to either all or a portion of the present consumers grounded on our estimates of the earning power of the corporation.

J. B. Fisken: In providing for working capital, it is suggested that working capital should be provided to take care of doing a jobbing business. I do not think that is right. It seems to me that a jobbing business is non-operative, and that a utility engaged in a jobbing business should be allowed to make any profit they can, the same as other jobbers do. I have an idea that in making a valuation of any public utility, all non-operating property should be entirely eliminated. It has occurred to me several times, that the question of the value of the service is quite an important one. I assume a case of two communities served with the same quality of service. Take the case of an electric power service. One community is served by a company buying their power at a very low figure from another company; this does not involve any expenditure for generating plant. If their charges for service are based on their investment, of course, the people living in that community will get a very low rate. Ten miles away from that community, there may be another one which has not been fortunate enough to make a contract to buy power at a low rate, and has to invest in an expensive generating plant; that community may have to pay twice as much as the other one, and yet the value of the service is the same. Now, it has also occurred to me, as to what constitutes confiscation. In the west, I believe, it is generally acknowledged that an 8 per cent return on an investment is reasonable. Now, if a regulatory commission should reduce the valuation of a utility's investment so that their return is cut to 4 per cent on the actual investment, it seems to me that it has confiscated half of their capital, and in making a valuation of a property I think it would be very much fairer to make a sufficient inventory and investigation to establish whether or not the utility has watered its stock. If the utility stock is not watered, if they have been careful in making their investments, I can not see where there is anything to be gained by making a detailed inventory. All that a commission should find it necessary to do would be to make sufficient inquiry to satisfy itself that the investment has been carefully made.

John H. Finney: I would like to inquire what 8 per cent return means as applied to a public utility? If it means net

return to capital invested and is fixed as a maximum which capital is to be permitted to earn, there is not going to be, in my opinion, a great deal of either hydroelectric development or public utility development in the near future. If you pay 6 per cent for money, 8 per cent is not going to give the concern operating and building up the enterprise a profitable or adequate return.

A proposition cannot be financed where such an unfair and inadequate limitation is imposed, and if it is an existing concern and such limitations are imposed, it cannot hope to live and thrive for long.

David B. Rushmore: The interest attending the regulation of economic activities is not confined exclusively to those associated with public utility and railway enterprises. The signs of the times all indicate that manufacturing companies and, later, mercantile and other enterprises, will all receive state or federal regulation.

Without question, the production, transportation and distribution of commodities will come under the same governmental restrictions as are now attending the same features in connection with electric energy or transportation.

The important feature to be borne in mind in connection with regulation is the definite object to be attained, and this should necessitate the clear enunciation of certain fundamental principles. It would seem that up to date these have not been distinctly stated.

It is important that we should know the fundamental principles underlying regulation or rate making. Will it be possible to decide all of the important questions involved unless some agreement is previously had on such fundamentals?

The items which make up the cost of product are so involved and so difficult of determination, that people not familiar with these subjects at first-hand are met with very great difficulties in their attempts to treat the subject intelligently. We must assume a desire on the part of all individuals to do what is right. The difficulty is, of course, to determine what that is.

Working capital may be considered somewhat in the nature of the auxiliary reservoir at the top of the high head pipe lines of hydroelectric plants. Due to the fact that any additions in the future are necessarily subject to some uncertainties, no one would wish to run a hydroelectric plant or a commercial enterprise with too great or exact a limitation put on the working capital or the reservoir capacity on which they can draw to meet unexpected requirements.

L. B. Ready: The question of investment often bothered me to know just what we should include. Should we include interest during construction as reproduction value, or the amount which the company has charged to interest during construction, where the company has charged a lot of money to operating expenses which might be charged as capital?

Mr. Cory has not defined what should be capital, and I think it would help us greatly if we knew exactly what should be included in capital, in the question of investment, which should be included in capital under the question of reproduction cost, or original cost; and I would also like to ask what he means by the consideration of discount of bonds. It seems to me that the discount of the bonds and the payment of commission on stock is more a question of money to the utility, and should be considered in the rate of return allowed, rather than upon the investment, because a company may sell 5 per cent bonds for 80 per cent, or sell 6 per cent bonds for a hundred, and it is more a question of return rather than investment. And, under the investment, does he consider it—whether the preliminary losses during the development of the business should be considered as part of the investment, or as under the question of losses; for example, on the reproduction method—reproduction new. It would seem logical to consider the reproduction of the business, because that is a part of the going property; on the investment basis it would seem also logical to either consider that, or to consider it in the question of the rate of return. It necessarily follows that the investment or the reproduction value, reproduction new, is not a measure of the value, because property, in any sort of investment might not have a value commensurate with it. The company may have a value of a million dollars, and can not earn a return on a hundred thousand dollars, and as a result, there would not be a million dollar value. If we start in with the question of value first, based largely on the question of the returns, we are working without any rate, because the rate of return determined the value, and the value then determines the rates. There was one point in connection with the determination of the working capital. It appears to me in this paper it has been assumed that the company has spent its money as the month goes by, that the average money is spent in the middle of the month; but how should we handle a company that buys power, pays its bills at the end of the month, pays its employees at the end of the month, and pays a large amount of its maintenance expense at the end of the month? Should we then allow them the 15 days during the month as a part of its working capital in determining its working capital, while it does not pay its bills until after the end of the month, and really it only has the additional days on which the capital is considered as working capital. Then, there was one question on the paper submitted by Mr. Betts, in which he showed a percentage of 31.35 per cent of plant capital, and varying percentages. As I understood it, he included a part which might be considered development cost, interest on construction. Am I wrong about that?

C. L. Cory: Answering Mr. Ready's question as to the overhead percentages as allowed by Mr. Betts on plant machinery and equipment wherein the total percentage allowed is 31.35, the following statement is made in the paper:

"On the whole, I feel that an allowance of thirty per cent for the overhead charges in connection with plant machinery and equipment is fair."

In arriving at this percentage in accordance with the detail as set up in the paper, nothing is included which has to do with the value of the business or the cost of developing the business.

However, there are two instances as stated in the paper, marked with asterisks, to which the following note applies.

"Includes an allowance for development of business."

In these two instances the composite overhead percentage, including allowance for the development of the business, is, in one case 27.1 per cent and in the other case 31.3 per cent.

Referring to Mr. Ready's question as to whether an allowance for discount on bonds should be made in appraisal work, let us consider this matter from the following standpoint. Suppose Mr. Ready desires to lease a house for residence purposes, and proposes to enter into such a contract with me as the owner of the property, it being understood that the rent shall net me, after all other charges are allowed for, eight per cent per annum. Assume that it is necessary for me to borrow either all or a large portion of the money necessary to buy the real estate and to construct the house. Assume that financial conditions are such that in obtaining the money it is necessary for me to obligate myself to, at some definite time in the future, pay a thousand dollars, and at the time of making the loan get from the bank but eight hundred dollars. With this illustration I am only attempting to bring out a comparison with what actually happens when a public utility finds it necessary to issue bonds and receive from the investment bankers less than the face value of such bonds. It would seem clear, I think, that it would be necessary for Mr. Ready to pay me 8 per cent in the shape of rent on each $1000 which it is necessary for me to invest or borrow, since ultimately it will be necessary for me to pay $1000 for each $800 in cash which is expended in preparing the property for his use. Under such conditions the thousand dollar unit must be considered as the cost to buy the land and build the house, or to put it in another way, the investment is $1000.

Referred to the public utility in its method of financing, this is actually what happens when such public utility furnishes service to its customers. Of course very properly there should be introduced into such an arrangement the proper query as to whether the arrangement between the bank and myself is fair, or to put it in another way, whether this is the best and most economical method available by me to obtain the money required.

Again we have a direct analogy in reference to the discount on bonds and the interest rate on such bonds. If a borrower is willing to pay 10 per cent per annum he might be able to

obtain $1000 in cash for his $1000 note, but on the other hand financial conditions might be such that if the interest rate were reduced to say 6 per cent or possibly 5 per cent the investment banker would require a payment of $1000 in the future, although but $800 was received by the person borrowing the money.

If, then, the investment is to represent actually what it cost the public utility to provide the necessary equipment to give service, it is necessary to take into consideration what the money needed for such construction actually cost, and it is well to remember that money is a much more vital element in providing service to the public than is Ohm's law or any other physical law. It makes little difference whether we have communication of intelligence across the continent by the use of the present telegraph or telephone systems with thousands of miles of pole lines, or whether we have the same communication of intelligence by wireless. Money will be required in the building of such systems, and it is purely academic, and to my mind foolish, to limit ourselves to a definite restriction as to how this service is to be rendered.

Value is very closely related to the rate of return upon the investment. If, for instance, one public utility in a district can furnish electrical energy at one-half cent per kw-hr., while another finds it impossible to furnish the same service for less than one cent per kw-hr., the value of the first utility under any circumstances must be greater than the value of the second utility. Whether or not rates are regulated has nothing to do with this economic question. The amount of business which is done will depend upon the cost of the product, and the cheaper the commodity can be delivered to consumers the greater will be its use. If, for instance, in the near future means are found so that we can carry on conversation between San Francisco and New York, and the cost of such service, assuming that it is equally satisfactory, is one-fifth of what it costs under present conditions, it is useless to maintain that the value of such a system is not greater, independent of its cost, than those in use under present conditions. One matter of importance must be borne in mind; it is always of the greatest advantage to civilization, to the people interested in public utilities, and to the customers of such public utilities, that the best possible service be provided at the least possible cost, not for today only, however, but for all time.

Therefore any unnecessary restrictions prescribed by a rate fixing body, which in the end permanently retard the development of such public utilities is just as serious a disadvantage to civilization as it is to those interested in public utility development.

No one desires cheap service. What is desired is good service under conditions whereby every requirement of the people will be met not only today, but for all time.

In conclusion, I wish to add a word as to the value of public utility properties. In the past we have adopted a lot of artificial methods of attempting to arrive at value, when of course ultimately the value is quite independent of cost, but depends very largely upon the net rate of return which is obtained from the sale of the commodity. After all we are trying to get evidence in all these cases which will lead us to a conclusion as to the amount upon which a certain rate of return shall be allowed, and no considerable progress can ever be made if in any way value is considered as the equivalent of cost to reproduce new, original cost, or similar terms with which we are all familiar.

There are cases which come before us, however, which are not essentially rate cases, wherein we may desire to obtain as nearly as possible the investment, or in other words the cost of reproduction today, and still others obtain as nearly as possible a figure representing the cost to reproduce an absolutely new plant physically different from an existing plant, but one capable of giving the same service. In all these cases, however, we are simply attempting to obtain evidence which will lead us ultimately to an approximation of the value of the property.

Discussion on "Diesel Engines for Generator Drive" (Legrand), San Francisco, Cal., Sept. 17, 1915. (See Proceedings for August, 1915.)

(Subject to final revision for the Transactions.)

Wilfred Sykes: It will be interesting to find out what Mr. Legrand's experience is with the engines after they have been running for some time. From observations made in Europe I got the impression that considerably more attention had to be given to these engines than to other types of prime movers. The class of people used to operate them seem to be much better than is usually found in power houses and undoubtedly they are paid more money for their services. The successful Diesel engines seem to be those with comparatively small cylinders. The engines developing about 200 to 250 h. p. per cylinder run entirely satisfactorily. As the size of the cylinders is increased difficulties in manufacture and operation also increase. As far as my observation goes it is essential for the success of Diesel engines that they should be strongly built, should have good workmanship and not have too much power per cylinder. The attempts that have been made to build light Diesel engines such as are required for submarines have not been very successful. From the standpoint of reliability, a light Diesel engine has not given the service that would be considered satisfactory for land work. They have been used for submarines mainly because nothing better was available. Attempts are being made to get away from this type of prime mover where light weight is essential, and it is probable that in the near future the Diesel engine will be superseded for submarine work by the steam turbine, although the economy of the latter is not as good as that of the Diesel engine. In a number of plants which I investigated it seemed to be the common practise to take out the exhaust valve every week, and the statement was made that although very often there was no apparent reason for doing so, it was found that by following this practise and anticipating any troubles that might occur, more continuous service was obtained.

D. W. Beldon: I spent a few hours at this installation of which Mr. Legrand speaks. The operation of the engine up to that time was very satisfactory. Some minor mechanical troubles appeared in the valves and other parts, but that was all. This installation is not the largest one in the United States. After they had used the engines a few months they ordered a duplicate. This indicates that the users have a great deal of confidence in the engine after all. Fuel conditions at that particular location entered into their considerations in deciding on this type. Oil from the Texas fields can be secured as well as from the California fields. The Texas oil is more satisfactory for use in these engines. The California product is a little cheaper, and they are trying them out with this low grade oil to be certain that they can run on a heavy asphaltum base oil.

J. C. Clark: It seems to me it is rather unfortunate that the current readings were so small that reliable data on the inter-

change of current between the generators are not available. Of course it does not mean very much that the variation of load between generators would not be shown on an indicating watt meter.

W. D. Peaslee: The use of Diesel engines on the Pacific coast has been rather limited; about a year and a half ago I had occasion to investigate a Diesel engine in connection with the installation of a pumping plant requiring about 300 h. p. I had the matter up with two or three of the manufacturers of Diesel engines, both domestic and foreign, and while they were willing to give very fine guarantees as to fuel consumption per b. h. p-hr. on the test, and such things as that, they were wonderfully silent when it came down to questions of how much it would cost to run per h.p-hr. at the end of two years.

On the question of attendance, they said, "You can step out of the office in New York and put an advertisement in the paper and in the moring have ten men who can run the engine." Can they do that on the Pacific coast? I doubt if we can pick up ten men who can go out and run a Diesel engine and keep it in shape.

I am sure all the engineers on the Pacific coast are in the position of wanting to know. We are not antagonistic to the Diesel engine, but we are not going to spend a lot of money to put in equipment until we know what it will do. I think it should be the policy of the committee to get the manufacturers to give us a paper showing some data on their installation, especially in Europe, giving data as to how much it costs to run the engine after it has been in service a while. We don't want to know how much it costs the first six months, but how much it costs after they have been in service for several years. It does seem that the maintanence cost is bound to be very high.

A. H. Babcock: In my opinion the maintenance costs of Diesel engines are no longer uncertain. Either they will be very low or very high. The only engines with which I have had personal experience are those in the Southern Pacific shops at Ogden and at Tucson. Both were built some years ago by an American manufacturer, who built on European designs but under American conditions of manufacture. Both were lacking in reliability and both turned out to be utterly useless for this reason, and because of very high maintenance costs.

In sharp contrast with this experience the record of the first motor ship to reach San Francisco is cited—the steamer Siam, a 10,000-ton ship equipped with two Diesel motors, 1600 h. p. each, that is to say,—eight 200-h. p. cylinders. She carries fuel for 125 days ordinary running, or approximately 30,000 miles. The fuel is carried in the double bottoms. The absence of the usual boiler room and coal bunker space adds 1000 measured tons cargo carrying capacity. Between launching and arrival at San Francisco she had run 40,000 nautical miles with no repairs to motive power save the usual regrinding of valves, which was done by the engine room force. On the voyage from Antwerp

to San Francisco she ran 39 days without slowing or stopping the engines for any purpose; then there was one delay of 16 minutes to one engine to change one of the valves. Her fuel consumption is 10 tons of oil per day, while a steamer of similar capacity would use 50 tons of coal. The engine room force is 12 men all told. A similar steamship would carry 40 to 50 men. The only steam used on the ship for any purpose whatever is a small donkey boiler for heating the cabins in cold weather. The ship carries very few spare parts, although at times she is very far distant from her base of supplies. The motive power costs about one and one-half times as much as for a similar steamship, but the increased cargo space, saving in engine room maintenance and crew wages and maintenance, more than make up the difference. These facts, taken from the engine room log of this ship, afterwards were corroborated by similar records of other boats. The maintenance and the operating costs of the engines of these vessels are everything that could be asked, and their reliability is beyond dispute.

I have tried for a number of years to find opportunities to use Diesel engines in the work with which I am connected, and I have failed every time, not on account of uncertainty of maintenance costs, not on account of low fuel economy, but solely because the fuel that we could use in those engines we can use elsewhere in steam plants under conditions that enable us to work out a financial economy superior to the Diesel engine financial economy, merely because the fixed charges that lie against the Diesel engine plant are so high that they overbalance completely its high thermal efficiency.

M. H. Gerry: I was very much interested in the remarks of the last speaker. I would like to ask him if he thinks that the high cost of the Diesel engine is not in part due to the development costs that are at present connected with it. If it is an inherent cost, then there will be no probability of future reduction. If the development costs are still the item that increases the cost of the Diesel, then in time those costs will be reduced in the final cost of the Diesel engine.

A. H. Babcock: I have had correspondence with at least three foreign manufacturers who will be very glad to furnish Diesel engines of almost any capacity, for which a purchaser can find floor space; this being usually the limiting condition of engine size. They will furnish these engines at a fair shop profit, the overhead expense being low and the development charges having been spread over a considerable output.

But nevertheless, my correspondence showed here, as before, that for stationary work with average load factor, the fixed charges command all the fuel and labor profits.

William H. Rost: In regard to picking up men capable of handling the Diesel engine on the Pacific coast, or anywhere else, even in as remote a place as Alaska, the experience I have had is that it does not require an engineer. A man of ordinary

intellect, can run them. It does not require any mechanical ability at all. I have taken men right off the street. As far as electricity is concerned, they knew nothing of it; as far as mechanical ability is concerned, scraping, repairing or taking care of a hot bearing, they knew nothing about it. I have taken men of that calibre and showed them how to start and stop the Diesel engine. That is the most particular point—starting and stopping the Diesel engine, and conscientiously keeping the engine oiled. In ten days time, starting and stopping the engine twice a day, 150-h. p. engine, they had no trouble at all. This is not simply one case, but there are three cases. We have two engines in San Francisco that are running 24-hr. a day, and one man, a machinist, with a little shop experience in the way of helping to erect the engine is the only man we give credit for knowing something about the Diesel engine. The other men not only have the engine but they have the whole ice plant to look after. The engineer is in the engine room very little. The oilers practically take care of the engine, and with the exception of one man who has had considerable experience in attending to steam engines, the other two are young boys who have had little experience. Steam engineers have taken hold of the Diesel engine in elegant shape.

What I want to impress on you is the simplicity of the Diesel engine. A man has got to have a great deal of experience to look after a steam engine plant properly. The steam engine itself will keep up about as well as a Diesel engine; it is just a matter of lubrication. The boiler, of course, requires a great deal of attention, and the man in charge of it must have the knowledge as to how to do the work, how to keep it in repair.

The men running these engines were given their instructions, and the engines were turned over to them in 30 days time. There are three shifts, running day and night. The engines have been running now nearly a year and a half, and they have not called on us in any way in the last year in regard to any question or anything of that sort regarding the Diesel engine. Inside of three or four months they took the whole thing over and handled everything themselves, even changing the valves.

This summer the engines have been running continuously for days at a time, 10 per cent overload, and the valves have remained in those engines 40 to 45 days without being removed. We advocate removing the valves about once a month. If I was running the engines myself, I would take the valves out a little oftener than that, because I think it is an extra precaution, and eliminates much grinding.

When it comes to repairs, I will say that the first head was removed from one of the engines this week. The heads have not been removed in a year and a half of running.

Very few spare parts are carried. These include an extra set of crank pin brasses and an extra set of main bearing shells and these have not been called into use. They had one extra set of valves

to start with and ordered another additional set in order to have plenty of time to have them turned down and ground in. I believe they have an extra fuel valve needle and a few spare valves for the compressor and some piston rings. They have never been called upon to use any piston rings.

We have had some experience breaking in engineers in Alaska, and we have not had any trouble in finding men to operate the engines. That is the point I want to bring out. If a man knows a little about keeping his valves tight, if he knows a little about the principle of the gas engine, he understands the principle of the Diesel engine. He has no carburetor troubles; he has no spark troubles. We have never had any trouble from lack of compression. When you can find men in Alaska you can pick them up in San Francisco.

M. H. Gerry: The weights are rather heavy per horse power. My recollection of the cost of Diesel engines was that the price per pound was rather high. Isn't that a fact?

A. H. Babcock: Yes.

M. H. Gerry: If the price per pound is rather high, it would indicate that the development charges still bear a relation to the total cost, and we could look ahead to a better condition, in other words, to final lower costs for Diesel engines.

William H. Rost: Absolutely.

M. H. Gerry: If, on the other hand, the cost per pound were normal, as compared with the price per pound of engines of other types, there would be little hope of future reduction in the cost.

A. H. Babcock: The Diesel engine runs at extraordinary high pressure, somewhere around 30 atmospheres air pressure in starting. Probably the pressures at the instant of maximum combustion would be somewhere around 1000 lb. to the sq. in. Therefore, very strong construction and very high class material is necessary.

As bearing directly on the fixed charges, I will ask you to remember this, that in general the successful Diesel engine we hear of is operating with a very high load factor such as a vessel at sea for 30 or 40 or 50 days, or an ice plant running practically continuously 24 hours a day. Those features make it possible to spread the fixed charges out over a larger number of units and bring down the unit cost. It would be utterly impossible to figure any economy whatever in this sort of installation with the railroad load factor or even the ordinary railroad shop load factor where for four hours in the morning or four hours in the afternoon the load would be fairly constant but in the other hours of the day, rather low.

G. M. Eaton: Mr. Babcock stated that the troubles experienced with some of these early engines were because the engines were manufactured by American builders who, following our usual practise, attempted to cheapen; and that resulted in very high maintenance costs. Did they succeed

in so reducing the cost that had the maintenance been reasonable the engine would have been a practical proposition? After all, these American builders were following the curve that must be followed if the Diesel engine is to be used largely in our work.

A. H. Babcock: I will answer that question by saying that in both cases the shut-downs were due to machinery failures generally, and with a single exception were not confined to any special details, for example: In the first year of operation at Ogden the engine was out of service 2 months continuously on account of a broken crank shaft. In the second year it was out of service 26½ hours, in the third year 28 hours, and in the first month of the fourth year 35 hours; a month later it was replaced by an electric drive. The engine gave continuous trouble and practically every week-end was spent in a more or less complete over-haul in order that it should be able to run the following week. A similar engine was placed in the Tucson shops at about the same time. It was kept in service 14 months, in which its days out of service were 174, or 44 per cent of the total time; and the engine was replaced by electric drive for practically the same reason as at Ogden. Furthermore, these engines will not use the ordinary crude oil fuel, but have to be supplied with a more expensive lighter oil. On the other hand, the Siam on her first voyage to this coast used Sumatra oil, which she had taken at Borneo on a previous voyage. At San Pedro, purely as an experiment, she took residuum containing 54 per cent asphaltum. She left San Pedro with the Sumatra oil in use, but when she reached the open sea the change was made from the Sumatra oil to the San Pedro oil. The only effect was to speed up the engines, there being more heat units per pound in the heavier oil. I saw her both maneuvering around the docks and under way using this oil. There was no trouble whatever in handling the engines. Repeatedly they would be changed from full speed ahead to full speed astern in less than seven seconds. The reversal was always prompt and certain. Before she left San Francisco this oil was changed for a lighter fuel, more nearly like engine distillate, and a great deal of talk resulted. The reason of the change was that from here she was ordered to Vladivostock. The oil, being stored in the double bottoms without means of heating, it was reasonably certain that going into that cold climate in mid-winter was sure to result in trouble, because to put what was practically tar into ocean temperatures in mid-winter probably meant to pick it out rather than pump it out; and the fuel taken here was better adapted to those conditions. It was a case of either putting heating means into the fuel tanks or changing the oil, and the owners decided to change the oil rather than to change a single pipe in the ship because of the gossip that would result if it became known that any part of

the vessel's outfit had been changed. Opponents of this method of ship propulsion certainly would exaggerate even a heating pipe change, into extensive repairs. Many rumors of trouble did start, for example: It was reported in the San Francisco papers that she had broken down on the way and was lying disabled in a Japanese port. The facts were that while lying at anchor in the harbor of Nagasaki she was run into by another vessel and her hull was slightly damaged. Lately I have not gone aboard motor ships reaching this port, because it is always the same story. There is no question as to reliability of operation of these vessels.

W. D. Peaslee: The statement a few moments ago as to the ease of getting operators, brings out exactly the point I wanted brought out. We had a plant in the northwest about three years ago and picked up operators like that, and it ran for two years, and they have had a great deal of trouble with it and have thrown it out. I have seen it since it was discarded. It shows the wear and it shows the effects of the expert operators that were trained in ten days, taught to start and stop and oil the engine.

There is no doubt that the high cost of these machines is the controlling factor in their installation; but at the same time we must remember that operation is a vital point. You take a machine that costs as much as one of these Diesel engines and the mere fact that it runs a year and a half satisfactorily with any kind of a man handling it, is not enough for us. We know we can take a good boiler and good steam engine and put a good man on it and it will do good work for a lot longer than a year and a half or two years and a half or five or ten years. The point I first made and want to emphasize is that we have no operating data over an extended length of time. The primal fact is that Diesel engines cost too much money.

In these ships that come here the engines were built by the foreign manufacturers and cost a lot of money. They are manned by men whose technical training is probably superior to most of the men operating steam plants in this country, and they are kept up as all the machinery in the old country is.

It should be emphasized that besides the prime objection of very high cost, we have not yet sufficient data to know that we can operate these engines successfully with the type of operators we have in this country.

Mr. Landsberg: The question has been asked about the weights of the engines. I think those engines without the generators weigh 132 metric tons and are 1200 h.p. at sea level. The engines cost about $50 a h.p. in New York.

W. H. Rost: When it comes to starting and stopping a Diesel engine and giving the service that is required of the engine, an operator can do it with very little training; but when it comes to taking down any Diesel engine and giving it a little overhauling, it takes an expert mechanic.

R. Tschentscher: High pressure Diesel engines, I understand, are said to operate at about 30 atmospheres. I think that will be reduced in the same way that it has been in gas engine practise. They were formerly practically 30 atmospheres, and now the maximum pressure in a great many installations is not over 20 atmospheres. That will tend to reduce the cost per pound and the total weight of the engine.

M. H. Gerry: I always feel that with better manufacturing facilities, with the development costs finally eliminated, and manufacturing on a larger scale, that the unit costs will finally come down. Machinery finally comes down to just about a certain level in the end although it may take a number of years to do it.

Discussion on "Experimental Data Concerning the Safe Operating Temperature for Mica Armature-Coil Insulation (Newbury), New York, Nov. 12, 1915. (See Proceedings for October, 1915.)

(Subject to final revision for the Transactions.)

Philip Torchio: One of the points which was the subject of much discussion by the Subcommittee on Rating last year was the question of determining in the standardization rules the safe temperature limit of mica insulated windings.

Evidence had been presented that mica insulation, unlike other insulating materials, could safely withstand indefinitely temperatures of 150 deg. cent. The results were obtained from laboratory tests, though by inference it was surmised that mica insulated windings of certain machines had probably operated safely for years at temperatures of about 150 deg. cent.

The advocates of the higher temperature rating, therefore, recommended the adoption of a standardization limit of 150 deg. cent. The more conservative nembers of the committee claimed that such limit was too radical a departure to adopt foı standard practise, and contended that such a high limit should not be adopted in the design of machines without any reservation. The committee finally reached a compromise by adopting a standard temperature limit of 125 deg. cent., with the proviso that special machines with higher temperatures should be specially guaranteed by the manufacturer.

As things will happen, I was personally one of the strongest advocates for keeping the limit at the low value of 125 deg. cent. and perhaps the first engineer on that cómmittee who soon after actually accepted guarantees of 150 deg. cent. and over. This was in connection with the United Electric Light & Power Company purchase of two 20,000-kw., 3-phase, 25-cycle, 6600-volt, 1500-rev. generators to be operated single-phase to furnish power to the N. Y., N. H. and H. R. R. The armature windings are insulated with mica. The generators are guaranteed both for 3-phase and single-phase operation. One guarantee, by thermometer and resistance measurements, provides for continuous three-phase rating of 20,000 kv-a., at 6600 volts, with temperature rise of 50 deg. cent. in armature and fields and also for continuous 14,300 kv-a. single-phase load, 70 per cent power factor, with 55 deg. cent. rise in the armature and 65 deg. cent. rise in the field. The other guarantee by thermo-couple measurement, provides that the machines will carry continuously 14,300 kv-a. single-phase at 6900 volts and 70 per cent power factor, also 25 per cent kv-a. overload at 65 per cent power factor for seven minutes succeeding the continuous run and 50 per cent kv-a. overload at 60 per cent power factor for the next two minutes with temperature rises in the insulation within the armature slots of less than 100 deg. cent. with possible local hot spot rises of 120 deg. cent. With 40 deg. cent. room air temperature, this latter would give a temperature of 160 deg. cent. as measured by thermocouples.

The generators shall withstand an insulation test of 30,000 volts for one minute. In addition, the coils before being placed in the core, shall withstand an insulation test of 45,000 volts for one minute.

The generators are designed for ventilation from external motor-driven blowers.

The field coils are wound with copper straps in slots and are insulated with asbestos and mica to withstand a temperature of 150 deg. cent. without injury.

In purchasing machines under the above guarantees, it must be noted that we had also in mind the fact that the conditions of service would not require the maximum possible output by the generator in the form of a continuous load. Instead, the maximum demands are intermittent and usually are periods of short duration, like the time required for accelerating trains. The two overloads specified in the guarantees for the length of duration given are not likely to occur more than occasionally during the operation of the machine. Hence, the machines will not operate continuously at the maximum temperatures, as would be the case with the generators for supplying central station lighting and power loads.

Mr. Newbury's results would indicate that we could operate the machines at temperatures in excess of 160 deg. cent. If we should allow temperatures in the order of the Niagara generators, it seems that it might be possible for us to carry continuously single-phase kv-a. loads of over 16,000 and overloads of over 25,000 at 60 per cent power factor. This would be a great advantage to us in carrying possible overloads in emergencies.

One point that must be made clear is that in the adoption of mica insulations in the design of machinery, like the machines I have described, the object is not to reduce the cost of construction. On the contrary, this type of insulation and the design of machines are such that the cost per kw. is probably higher than for other machines insulated with fibrous materials. The question at stake, however, is the fact that, on account of high peripheral speeds, required for economy of steam, and limitations in the strength of materials, the dimensions must be reduced and the heat radiation sacrificed. Hence, the necessity of introducing insulating materials capable of withstanding high temperatures.

From another standpoint—in the design of turbo-generators for single-phase railway loads the importance of obtaining machines of the greatest overload capacity in kv-a. at low power factor makes it doubly necessary to keep the generator dimensions to a minimum, so as not to unduly sacrifice the all day steam economy, as, if an unduly large machine is installed to provide capacity for kv-a. overloads at low power factor, the extra iron and the field losses in the machine will materially affect the average steam efficiency of the unit.

I would praise the conservatism of the Standards Committee

in providing that machines of this character be subject to special guarantees by the manufacturers. The purchaser also should exercise due care to see that every point in the design is covered by liberal margins in insulation and possibly in the installation he should provide protective devices which will minimize the electrical and mechanical stresses on the machines while in operation.

In the installation above referred to for supplying the N. Y., N. H. and H. R. R. service, the machines, as stated, are operated at 6900 volts, the current being stepped up to and transmitted by underground cables at 24,000 volts to the point of delivery and there again the underground and overhead lines are separated by ratio 1.1 transformers. These transformers provide a liberal protection to the windings of the generators. In other cases the reactance coils on the generator leads are installed. By these provisions the possible damages of shocks due to short-circuits affecting the insulation are minimized.

The experience of the Niagara generators would be of very little value in giving information as to what would occur on similar generators designed to operate at 11,000 volts instead of 2200 volts, and under conditions of fluctuating loads with occasionally heavy short-circuits. With 2200 volts even a cracked mica insulation might last indefinitely, while it would soon break down if operated at higher voltages.

I understand also that the Niagara generators had a very large internal reactance, which naturally reduced the stresses on the windings; also the windings were made of solid bars giving great rigidity, while in modern generators of larger capacity the windings are made up of smaller copper having less rigidity to protect the mica insulation from cracking once the binding material is charred.

The turbo-generators I mentioned are the largest single-phase units in operation, they being somewhat larger than the generators of the Norfolk & Western Railroad. The results of accurate tests of these machines have not yet been obtained, but when available they should be carefully studied, as they will furnish information of immense value for the design of generators of very large capacity, and especially for those applications which require the use of single-phase power.

W. J. Foster: Mr. Torchio has called attention to a very important application of mica insulation with reference to temperature limits, viz: the case of the single-phase turbo-generators. Another field of application with which I am familiar, is the case of frequency-changer sets connecting two large systems. Such sets are often made with only two bearings and have very large shafts between the two rotors to take care of the deflections, and consequently the torque that may be transmitted is high compared with the rating of the set. If both machines have all mica insulations, and if conditions should change somewhat, as more information is gathered, such as Mr. Newbury has brought

forward, and it appears safe to operate at high temperatures, the operator may increase his load by simply increasing the potential and the capacity of his exciters. It seems to me that it is wise for the Standards Committee to at once increase the temperature limitation of the Class B insulation from 125 to 150 deg. cent.

Mr. Torchio has called attention to the deliberations of the Sub-committee on Rating. On two or three occasions I was invited to sit with that committee, and I remember the discussion at that time as to the temperature that should be fixed for the different conditions. At that time I had some data gathered from experience which pointed to 150 deg. as being perfectly safe. Since then I have been able to gather more data from tests in the shop, carried out for that purpose. In one particular case, coils which were maintained at a temperature of 200 deg. for several weeks, and then tested while hot and the insulation examined, showed practically no deterioration. That of course, gives a margin of 50 deg. over what is proposed. There was another reason, which seemed to me a valid one at that time; that is, our engineering must necessarily depend upon commercial considerations to a certain extent. We are not able to undertake new machines or new enterprises except as orders are obtained, and the purchaser sees the thing in the same light as we do. It gives a far wider field for that type of insulation to have the limit at 150 than 125 deg. cent. One hundred and twenty-five deg. ultimate gives a temperature rise of only 80 deg., compared with 60 deg. in the Class A insulation, that is, 80 deg. as determined by the thermo-couple or temperature coil located in the slot. That is too small a margin to work on, to have many machines go out on a commercial basis. There are some machines, like those that Mr. Torchio has mentioned, that work-out better commercially, at the higher temperature with the mica insulation.

There is a little point in the data given by Mr. Newbury that I would like to inquire about, and that is an apparent discrepancy in the temperature as determined by the thermo-couple placed between the upper and lower bars at the center of the core in the second series of tests and the third series of tests; that is, in Table IV, and Table VI. In the first case the temperature rise appears to be 166.5, and in the other 185, and yet they are determined in precisely the same manner by thermo-couples. There is possibly some condition in the test which accounts for that difference.

The machines that I am interested in, and that I am familiar with, which have all mica insulation, have not been in operation many years. Thus far they are giving a good account of themselves, but I am not able to report concerning the temperatures which exist. I know that in many cases the loads have not been increased to the point that we had hoped for. These cases are mostly large frequency-changer sets, as mentioned before.

There are some cases of turbo-generators where the loads have not yet reached such a point that temperatures much above 100 deg. cent. actually are revealed. In these later machines, the temperatures are being taken by temperature coils located in the slots and the time may come when we can report on them.

I think it is in order at this time to call attention to the fact that while the field for the mica insulation may be large, yet it is desirable, to become convinced that 150 deg. is a conservative temperature to operate at, (150 deg. as determined by the methods of the Institute, which means the temperature of the hottest spot, whereas the temperature on the outer part would be quite a little below 150), to note that there still remains the desirability, for the best engineering, to use other types of insulation, and for more information, on other types of insulation that contain no mica whatever.

One of the earliest installations is near Montreal, where the machines have been operated for seventeen years without a single replacement of armature coil. We do not know what the internal temperatures are as we have no means of determining. I merely wish to point out the fact that there are other machines which have stood up well and have had long life, well on towards twenty years. Another case I have in mind is up in the Mohawk valley, at Tribes Hill, on the Fonda, Johnstown & Gloversville Railroad. I called up the chief engineer the other day and asked him if he would tell me when his machine was put in operation, and he said the first of them was installed in 1901—all of the machines were operating by 1903, and they had not had a single replacement. In fact, he said he had not spent a cent on them, and he wanted to know if he should use some varnish on the end of the coils. These machines were wound for 13,200 volts and have no mica. I wish to call attention to these machines, because if machines are properly made within the temperature limits of the insulation they will have long life.

There is another point which occurred to me as Mr. Newbury was referring to the matter of the eddy current losses in these machines. It would be a good thing, if it were possible, in that particular plant to test one of these generators for load losses by the method approved by the Standards Committee, namely, the short-circuited losses in order to find out whether the short-circuited losses as determined by the standard method would not just about agree with Mr. Newbury's estimate of what the eddy current losses in the conductors are. That could be carried out I think without much expense.

B. A. Behrend: Mr. Newbury's paper shows that electric generating units have operated for many years successfully at temperatures which have always been considered unsafe. I think it has been known for the last fifteen years that these facts existed, but they were only whispered, and they would not have gone beyond the little clique of those who actually knew about them.

The paper describes a generating unit of which a great many are operating at these high temperatures. These units have stood admirable service, they have taught electrical and mechanical lessons which have been the guide to the designers of large units. They were at the time of their installation the largest units of their kind.

The regulation of the units at Niagara Falls was very poor—their short circuit currents were very small and the strains produced on them by conditions of change of load were also comparatively small. All this must be borne in mind. It is a different matter to reason from the facts as presented, in regard to the old generating units at Niagara Falls, to the units of the United Power Company, or the Norfolk & Western Company generators, or the N. Y., N. H. and H. R. R. generators. It is a different question whether there is one conductor per slot or two conductors per slot solid and rigid, the conductors being wrapped in such a manner that, with the increase in temperature, the mica becomes more solid, or whether, in loose coils consisting of many turns, the vibrations of which may cause trouble, eventually leaving the mica in a different physical condition from that in which it was when the machines were constructed. The mica itself may not undergo physical change, but the mica is pasted together, and the binder becomes brittle, leaving the mica flakes without substance. Yet innumerable generators and motors with coils consisting of many turns and insulated with mica have stood very high temperatures for years. Therefore, Mr. Newbury's conclusion is, I believe, thoroughly sound, viz: that it is advisable not to draw the temperature limits too low.

H. P. Wood: When a temperature is allowed that destroys the strength of the binder or entirely eliminates it, the mica is liable to shift due to vibration, expansion and contraction, be damaged by the machine windage or be torn where exposed at the edge of the core by the compressed air used in cleaning, any of which mean the repair crew.

Examples are numerous where the present conservative temperatures have caused trouble from broken soldered joints or fractures due to crystallization and as such troubles increase with the allowed temperatures, to increase the present temperature is to sacrifice continuity of service to a theoretical ideal.

C. F. Scott: It is rather remarkable, that this new standard of insulation should have come from the Niagara Falls machines. They are rather notable machines. Only a year or so before they were contracted for and installed, alternating-current had been introduced, but it had not been placed on the basis it occupies today by any means. In fact, these men of the Niagara Falls Power Company had not officially decided that alternating-current, instead of direct-current, would be used in their plant until the summer of 1903 I believe it was finally decided at that time to use polyphase alternating-current of 25-cycles in that notable power plant, the largest electrical undertaking in the

country, if not in the world, which put electrical operation, electrical power generation and transmission, on a new basis. Before that it had been rather experimental or in rather small units. So far as I now recall the largest alternators at that time in this country were 375 kw. Those at the World's Fair were 10,000 h.p., but they were made of two single-phase machines, with their armatures set at an angle, so that really the largest individual machine was 375 kw., and it was a large jump from that to 5000 kw. We now find these machines are run very well. Mr. Imlay, when I last saw him, spoke to me about them and gave some figures on the repairs over the period they had been operating. The repairs were some small percentage, practically nil.

Now, we find incorporated in that first machine, was a kind of insulation which has done so well we can now marvel at it and it proves a new standard to be adopted now. You must remember that 2200 volts was pretty high then, and the designers, Mr. Lamme and Mr. Smith determined they would use the best material they knew of, and use it in the best way, and use plenty of it.

H. F. Erben: Mr. Newbury's object in presenting this paper was to lay before the Institute and Standards Committee such data relating to high temperature insulations that they would unqualifiedly raise the limit from 125 to 150 degrees.

My experience extending over a long period of years, leads me to state in the most unqualified terms that I believe it is absolutely safe to raise the limit from 125 to 150 degrees. Just how much higher we can go with safety is somewhat problematical.

Mr. Newbury has suggested that it might be safe to raise the limit to 180 degrees or possibly 200, basing his suggestions on the fact that in some cases insulations have been operated for considerable periods of time at 200 degrees. I note also that there is an implied suggestion that it might be the best practise to use mica exclusively for all classes of apparatus. Now in regard to the first suggestion that, " it might be safe to operate at temperatures of 180 to 200 deg. cent.", I would state that such a practise would inevitably lead to trouble, especially in the case of high voltage machines. I base my statements on the following facts:

It is well known that shellac which is the material generally used as a bond begins to disintegrate at temperatures between 190 and 200 deg. cent. Water having a strong acid reaction is first given off and as the temperature is gradually increased oils begin to accompany the water. These oils have the characteristic of readily attacking copper. This process will continue as long as the high temperatures are maintained and we finally reach a condition in which the composite insulation has been reduced to mica flakes, carbonized paper, and disintegrated bonding material, that is the bonding material of shellac or varnish on which we have largely depended for our insulating properties

has disappeared and we only have left the mica laminations, the dialectic strength of which will largely depend upon the summation of the leakage distances.

The machines tested by Mr. Newbury have armature conductors insulated with a composite mica insulation of about 1/10 in. in thickness, which gives about twenty-two volts per mil. It is present practise to use thinner insulation. the voltage per mil being in the neighborhood of forty to fifty. Now it is very possible that the long life of the insulation mentioned by Mr. Newbury may be due to the combination of comparatively low machine voltage of 2200 volts, and low voltage per mil. Even if the bond of shellac or varnish were completely disintegrated the total leakage distances through the mica laminations might be sufficiently great to give an insulation that would be entirely safe. However, I do not think it would be safe to say that it would be possible to successfully produce insulations that would stand up for long periods of time if the temperatures were increased to 180 to 200 degrees with a voltage per mil of forty to fifty, and line voltages of 6600 to 13,200.

The advisability of the general use of mica as an insulation to the exclusion of other types of insulation, such as a composite one composed of mica and fabric, or one made up entirely of fabric, is a matter which must be settled by the merits of the particular case involved. If the character of the apparatus is such that the conductors will reach a high temperature, due to heavy overloads or to exceedingly high room temperatures, mica insulation is essential. If, on the other hand, the conditions of operation are such that the conductors will never reach a temperature higher than about one hundred to one hundred and ten degrees, then an all fabric or a composite insulation should be used.

As an all mica insulation is more expensive than one of the composite or all fabric type, I do not think the designer is justified either from a point of view of safety of design, or duty to his customer, to increase the cost of apparatus by using mica when it is not necessary.

Charles E. Skinner: Some one has referred here this evening to the "inner circle" and I fear has left the impression that there has been a lot of information in the hands of a few designers for many years, which they were not willing to divulge. I am very sure that many of the facts which have been brought out during the last few years in connection with internal temperatures have been almost as big a surprise to the "inner circle" as to those not in such close touch with the work. While in certain cases, such as that of the Niagara Falls Power Company, machines would be run until a certain degree of odor from the insulation was observed, neither designer nor operator knew what internal temperature this odor actually meant.

I am quite in accord with all that has been said this evening with regard to the possibility of safely going to a somewhat

higher temperature for Class B insulation than is now permitted as standard by the rules of the Institute, and I wish to endorse the figure of 150 deg. cent. as a safe figure. I am in accord with Mr. Erben in not caring to go to 200 deg. or higher at least for the present. Considerations other than the effect of heat on the life of the insulation must be taken into account.

We now know that many insulating materials which are considered heat proof, begin to lose their insulating qualities when temperatures which may not injure them mechanically are met, and we know that the dielectric losses are very greatly increased in many materials at higher temperature, and that these dielectric losses which may be neglected at normal temperatures may be of prime inportance at the higher temperatures.

I also wish to agree with one of the speakers who stated that we must not be carried away with the idea that because the Niagara generators have been insulated with mica, and because they have remained in satisfactory service all these years, that mica is the only insulation we ought to consider. In fact, there are many cases where mica insulation is inapplicable, and where it should not be used.

John B. Fisken: I really can tell very little about the matter of temperatures of armature coils, but the thought occurred to me, after I had glanced over the paper by Mr. Newbury, that some of us who are operating 2000 miles away from the source of supply, and have to face overloads of perhaps 50 per cent to 100 per cent, and spend some rather sleepless nights thinking of what is going to be the result of a possible breakdown in the morning, will be able to sleep a good deal better.

Something has been said on the subject of insulations other than mica insulations. I remember at one time when we operated two small machines, 400 kw., 150 volts. They had been operating for about eighteen years, and on one occasion, when there was a breakdown, they carried the load until the armature connections melted off. I do not think those were mica insulated machines. I mention that to show there are other insulations which will stand for a short time very high temperatures.

Another thought which occurred to me is the effect under high temperatures of the linear expansion. If the ends of the bars are held, then that expansion must be taken up in bending in the slot, with the result that the mica will be brought under very high compression and I should think under those circumstances that something serious might happen.

Then there is a question of whether a machine is running continuously at this temperature or whether it is running intermittently. In the latter case, of course, you will have the alternate contraction and expansion, with the possible effect of grinding the mica out and having it dissipated into the atmosphere in the shape of dust.

P. M. Lincoln: These Niagara generators were put into commercial operation about twenty years ago. It is almost im-

possible to look back over those twenty years and consider the tremendous development that has taken place in that time. These generators were about four times the size of the largest a-c. units that had been made up to that time, and the alternating current unit which was compared with them was the double-frame unit, which Mr. Scott has mentioned, so that each half of that double-frame unit was of the order of 1/8 or 1/10 the size of the Niagara units. That of itself indicates what a tremendous advance over the previous art these particular machines were.

I was in charge of them for about seven years. I will say that I did suspect the temperatures were higher than we were getting by the thermometers, but did not suspect they were higher to the degree which was actually found and obtained by these tests which were made by Mr. Newbury. Our information at that time as to temperatures was given us entirely by thermometers, and we know now that the actual temperatures which occur inside of the machine are very much higher.

There were many other things about the generators which we did not know at that time. One was the method of excitation. When the plant was first laid out the exciters were synchronous converters. A plant excited by synchronous converters must have some outside method of starting. We had a steam engine which had been running some two or three years without shutdown. The time came finally, when we absolutely had to shut down the machine to get the bearings tightened up. Before the engine was dismantled, I made arrangements with the Niagara paper mill to get current from them, in case we should shutdown while our steam engine was dismantled. Sure enough there was a short on the plant and everything went out. It was nearly half an hour before arrangements could be made to get enough current to start our plant up. Today we would not think of putting in a plant to be excited by synchronous converters.

Another thing which we found out, was the deterioration of windings. We felt pretty safe about short circuits because we figured the machines would give only 2.5 times full load current, and that would not do any harm. It was not until we had a good many short circuits on the machines that we suspected we got a good deal more than 2 or 2.5 times full load current. On one occasion we had a short circuit on a bank of six generators, and it was so violent that the bus, a round rod one inch in diameter and supported at five feet intervals, was permanently bent out of line five or six inches. I figured it would take from 100,000 to 200,000 amperes to do that. That fixes the instantaneous short of these machines as something like 15 to 25 times full load.

Another thing which indicates more than anything else the advance we have made in the twenty years since these machines were installed was our improvement in the matter of parallel operation. It is a fact we did not know much about parallel operation at that time, and wondered if there would be any

difficulty in paralleling these generators. We started on the 26th of August with the expectation of waiting for the parallel operation test, as only two of the machines were ready. One day the switchboard attendants got confused and threw the wrong switch and we found the machines were in parallel. We wondered how we were going to get them out of parallel. Instead of pulling the switch of one of the machines and letting the load stay on the other, we tripped the field circuit breakers of both machines simultaneously and then started up the load again on one of them.

There was one statement made by Mr. Newbury in his presentation of the paper which I would take exception to. He said that the rapid heating and cooling of these machines as indicated in the figures, particularly Figs. 5, 6 and 7, is due to the large losses. Now, the rapidity of cooling and heating of the machine has absolutely nothing to do with the amount of loss; that it is simply a matter of the rate of cooling compared to the mass of material in the heated part, and the machine will arrive at a given percentage of its final temperature in a given time independent of the amount of loss in those parts. I say a given percentage of the final temperature, of course, the loss does have an influence upon the rate at which the actual temperature increases, and not at which it arrives at a given percentage of its final temperature. That is definitely fixed by the mechanical characteristics and ventilation of the parts, and not at all by the amount of loss in the machine.

F. W. Peek, Jr.: I think, perhaps, it will not be amiss to consider collectively, in a general way, some of the principles involved in deciding upon the permissible temperature of insulation. My remarks will apply generally to all apparatus using insulations and not to generators alone.

In certain low voltage apparatus the necessity of using insulation other than air becomes necessary from the fact that a mechanical support and a dust and moisture proof cover must be supplied. When the voltage is low the dielectric stresses are negligible, and dielectric puncture is not possible under normal conditions. The support may, therefore, be of low dielectric strength, but its insulation resistance must be fairly high. A crack in the dielectric does not mean failure.

In apparatus operating at high voltage, and in apparatus directly connected to outgoing lines and thus subjected to lightning voltages, etc., high dielectric strength and high dielectric resistance is necessary. A crack means failure. We have found that brittle and dried out insulation is dielectrically comparatively weak on impulse and lightning voltage,—that it is badly shattered by such voltages.*

All apparatus directly connected to lines of high power are subjected to the mechanical stresses of short circuit. High

*F. W. Peek, Jr., "The Effect of Transient Voltages on Dielectrics." A. I. E. E., September, 1915.

mechanical strength is, therefore, essential in such apparatus.

It is known that, in general, insulation decreases in dielectric strength and insulation resistance as the temperature is increased. If the temperature has not been increased above a certain point this change is not permanent, but the dielectric strength is regained as the temperature is decreased. However, if these high temperatures are applied continuously, insulations dry out and become brittle and weak. The degree of brittleness, or the extent of weakening, depends upon the time of operation at high temperature and the type of insulation used. Insulation in this brittle state may be suitable in low voltage apparatus not subjected to lightning, or in apparatus where the mechanical strains are small. It is not suitable in high voltage apparatus.

If insulation temperature is carried to a still higher point the insulation may become carbonized or deteriorate in some way, so that it is unfit for use.

A review of the characteristics of the insulation, and of the different operating conditions, noted above, shows that the operating voltage, power, possible abnormal voltages, mechanical strains, allowable rate of depreciation, etc., must all be considered in determining the temperature rating of any given apparatus. Naturally, the one reason for considering the operation of insulation at very high temperatures, is the possibility of reducing the cost or of increasing the output of some particular apparatus. In this respect the insulation temperature is not the only determining factor—the whole design must be considered, otherwise the possible saving may be greatly over-estimated.

The question of insulation temperature is, therefore, not one that can be definitely settled without the consideration of what the apparatus is, where and how it is to be used, the operating voltage, etc. Data like those given in Mr. Newbury's paper will help to decide these questions, in a practical way. A temperature of 150 deg. cent. for the voltage and for the particular conditions imposed in this case is undoubtedly safe as has been shown by Mr. Newbury, and others in the discussions. Such a temperature is desirable if a saving in cost, which cannot be better accomplished in other ways, results.

T. E. Fowler: There is just one question I would like to ask Mr. Newbury before we close, and that is in reference to Table IX. To what part of the windings do the temperatures therein refer?

There is another point which it appears to me might be well worth while looking into, and that is the question of temperature rise as given for the length of service of 100 hours in the latter part of that Table IX. Mr. Newbury gives it as 245 deg. to 285 deg. Probably a temperature of 250 deg. would be the maximum, because that length of service of 100 hours would probably be split up into a large number of small periods, in other words, it would be the apex of 100 hours rather than sustained periods, and consequently the temperature would not

follow the current exactly, of course, and would probably never reach a value of more than 250 deg.

W. L. Waters: There is one point which though not covered by the paper, has been touched upon, and that is in regard to the general advisability of the use of mica insulation. The general opinion as shown in the discussion seems to be that mica insulation is something new. As a matter of fact mica was about the oldest type of insulation which was tried. The earliest Siemens machines thirty-five years ago had mica insulation; and there are quite a number of firms who before and after the particular generator described in the paper was built, attempted to use mica insulation commercially. The obvious explanation as to why they failed is that mica has very little mechanical strength. It is a difficult material to manipulate as slot insulation. The Niagara generator with two bars per slot and the bar end connections insulated practically with air, is an ideal condition for mica; and there is no question than an extremely good mechanical and electrical job can be made on the armature winding of such a machine, which would be suitable for operation at high temperatures.

As Mr. Torchio pointed out that it is quite different when high-voltage wire-wound armature coils with conductors $\frac{1}{4}$ inch square are considered. Such a winding has not the required rigidity, and as the end connections are practically unsupported, trouble is liable to occur due to the mica cracking on account of vibrations or shocks resulting from lack of balance or short-circuits.

Before mica insulation can be considered commercially feasible on these high tension wire wound armatures, we require some information as to the actual experience of manufacturers with such generators. Mr. Newbury is probably in a position to give data on this point better than anyone else on account of his experience in the last few years with mica insulation; and I think we would be indebted to him if he would give us information as to the *actual operating results* obtained in such cases.

Charles F. Scott: If I remember correctly, the machines were guaranteed to have a rise in temperature not exceeding 50 deg. We found they did have 55 deg. We looked that matter up carefully, and the air vanes and blowers were changed and adjusted, and so on, and a careful measurement made, and we got down from 55 to $49\frac{3}{4}$, or thereabouts, which was considered safe, and it was accepted. If any one had supposed that we got down from 255 to $249\frac{3}{4}$ they would have been very much surprised.

E. W. Stevenson: With reference to the disintegration from the effects of the heat on the binder in the mica, I would like to ask if any of the members know of any other binder besides the particular binder that has been spoken about—some binder that will stand a good deal higher heat than 250 deg., somewhere around 500 or 600 deg.?

F. D. Newbury: In answer to the question asked by Mr. Stevenson, I do not know of any binder that can be used at

temperatures of 500 to 600 deg. cent. To apply mica wrapper tightly the binder must be sufficiently fluid, that the mica splittings can slide on each other. There are binders that will stand higher temperatures than 200 deg., but I do not believe they can be used in the application of mica insulation to armature coils, which, as several speakers have brought out, is not a simple process.

Mr. Waters asked about the comparative behavior of a coil made up of a large number of fine wires and one consisting of a solid bar. Armature coils consisting of wires, say ¼ in. square, with each wire separately insulated with mica tape, and with the several wires cemented together with a binder having a high temperature limit, have been constructed for numerous machines so that the complete coil has been very strong and rigid. In the large turbo-generators with which I am familiar such windings for high-voltage generators are practically as rigid as the low-voltage bar windings of the old Niagara generators.

The behavior of mica insulation when subjected to high temperatures under short-circuit conditions has been questioned. It has been suggested that the conditions in this respect were not severe in these early machines. Mr. Lincoln brought out the fact that very severe short circuits occurred during the operation of these generators. As a matter of fact, in some later machines of Westinghouse design installed in the same plant a much larger number of slots was used, with the result that the bars were thinner and weaker. In these machines the windings failed utterly under the severe short-circuits that occurred; that is, they failed until the ends of the bars, where they left the slots, were rigidly braced. The mechanical shocks which this winding has sustained in operation have been very severe.

Mr. Fowler asked a question in regard to temperatures in Table 9. They were measured by thermocouples in contact with the copper of the bar nearest the air-gap and at a point midway between the ends of the bar. He also pointed out that the temperature results for the maximum load between 1000 and 1100 amperes should not be given much consideration. I agree they should not, but not for the reason he advances. They shoud not receive undue consideration because the aggregate time of operation is so short. The load on the generator, when it did change, changed relatively slowly, and it will be noticed on the curves that the change in temperature follows a change in load very rapidly, so that I think whenever currents between 1000 and 1100 amperes are recorded temperatures between the limits corresponding to these loads actually existed.

Mr. Lincoln took issue with a statement I made in my introductory remarks concerning the reason for the rapid rate of heating and cooling occurring in this generator. I believe the complete statement in the text is correct. "The very rapid rate of heating and cooling of the winding shown by all of the graphical logs is due to the concentration of large losses in a small volume of

material and to the relatively low core temperature. In a modern generator of this size and voltage with a better distribution of losses, the difference in temperature measured between coils, and that measured between coil and core will be, as a rule, 10 to 15 deg. instead of 50 deg., as in Fig. 5, and, consequently, in more modern units the heating and cooling curves of the winding and core will very nearly coincide." Of course, the ventilation also affects this rate but in the Niagara generators the ventilation is fairly good. The *rate* of heating and cooling as measured in degrees per minute is what I referred to, and not the time required to reach a certain percentage of the final temperature as referred to by Mr. Lincoln.

Mr. Fisken referred to the possibility of the safe temperature being limited by the linear expansion. It is true that this may prove to be a limit with very high temperatures but this is not likely to be the case with a maximum temperature of 150 deg. It should be remembered that when high temperatures exist in the armatures of large machines they exist only locally, so that throughout the entire length of the bar the average temperature will be much below the highest point and the total expansion of course will depend on the average temperature.

Several of the speakers brought out the point that mica is not the only insulation that can be used when high temperatures are not involved. I did not mean to convey that impression. There are, however, certain cases where high temperatures are inevitable, and in such cases mica is the only material that will meet the conditions. As Mr. Erben pointed out, there are classes of machines where the expense of mica is not warranted. It is poor engineering to use an expensive material where the lower cost material will do the work, so that there is no intention in presenting this paper to put forward the proposition that mica is a universal insulation.

It was also not intended to advocate temperatures above 150 deg. for continuous service. I do, at the end of the paper, ask some questions that might justify such an assumption, and personally I believe that higher temperatures, will, with the accumulation of more data, be found permissible, but I do not believe that at the present time we have the data that will justify the Standards Committee in going to higher temperatures. Probably all designers know of machines in which they believe very high temperatures exist, but until they have experimental data showing that they do exist, it is impossible for other engineers to accept such cases as evidence.

Mr. Foster pointed out a discrepancy in temperature results shown in Table VII in the tests of 10/3/14 and 2/13/15. The results of the tests of Feb. 1915 were higher than in the previous tests. It should be remembered that these tests were made at intervals of several months and the windings were changed between tests so that some differences are to be expected. But the curves in Fig. 8 and Fig. 9 were plotted as the average of all

the tests, not as the maximum temperatures from a single test. The figures given in Table IX also represent these average results.

I was interested in the point Mr. Torchio made that a certain generator would be capable of carrying a certain large increase in load if temperatures equal to those of the Niagara generators were reached. Mr. Foster also mentioned this possibility in connection with large frequency changers. It is desirable to emphasize the fact that temperature is only one of many limitations to capacity. In any particular generator to obtain a rating consistent with these Niagara temperatures, it is probable that the magnetic circuit would have to be increased, the exciting voltage would certainly have to be increased, and as I have pointed out the temperature limit in the field windings of large high speed generators is imposed by the increase of resistance rather than by the characteristics of the insulation; that is, if 100 deg. cent. rise is greatly exceeded the increase in resistance and loss is so great that the increase in ampere turns, for even a large increase in exciting voltage, is very small. For example with an initial field temperature rise, by resistance, of 100 degrees the field temperature would have to be increased to 200 degrees and the exciting voltage increased by 60 per cent to obtain an increase of only 25 per cent in exciting ampere turns.

I also wish to emphasize the point that these high temperatures are not generally used to increase the rating or to decrease the size of machines. Where they have been used, certainly up to the present time, they have been a necessity due to the proportions of the machine. This is particularly true in large turbo-generators, in which high temperatures are a necessity if the highest attainable steam economy of the turbine is to be realized.

I have been gratified that so many of the speakers have agreed with the recommendation for a somewhat higher allowable temperature for mica insulation. There was one note of dissent from Mr. Wood. He argued that this increase should not be made because certain breakdowns have occurred, if I remember his communication correctly, even with our present limits, and that to jeopardize continuity of service for theoretical reasons is unwise. This recommended change is based on anything but theoretical grounds. It is the result of long years of experience that has led to a feeling on the part of some operators and most designers that these high temperatures have existed. Within the past two or three years we have been able to get at the real facts as to internal temperatures, so that this recommendation is the result solely of practise. We now know that these high temperatures have existed and, in this case, have existed for twenty years. Therefore, we can safely continue to employ them. It is not a change; it is what we have been doing, only now we have found it out.

To be presented at the fourth Midwinter Convention of the American Institute of Electrical Engineers, New York, February 8, 1916.

THE MUNICIPALLY-OPERATED ELECTRICAL UTILITIES OF WESTERN CANADA

BY A. G. CHRISTIE

ABSTRACT OF PAPER

The paper discusses a number of public utilities in various cities in Western Canada where practically all public utilities are municipally owned and operated. The characteristics of these cities are reviewed and a brief outline of equipments of the various plants is given. The costs and methods of financing these utilities are discussed at considerable length and the charges for various services are summarized. While the paper is not to be regarded as an endorsement of public ownership, the author finds that these utilities on the whole have been conservatively managed and have been practically free from political influence.

WHEN municipally-owned public utilities are discussed in the United States, it is generally held that these are open to the following criticisms:

1. The plant is not kept modern and up-to-date, resulting in indifferent service.

2. Rates are high in consequence of the preceding conditions.

3. The utility's finances are often poorly managed and frequently mixed with other city accounts.

4. The organization is indifferent and without definite lines of authority.

5. Politics are usually a factor in both organization and operation.

Mr. Halford Erickson of the Railroad Commission of Wisconsin has expressed very concisely the American point of view in regard to municipally-owned utilities, in a paper on "State and Local Regulation," an extract of which follows:

"Such utilities furnish no better service than privately owned or operated utilities. In fact, it is often a great deal worse. Municipalities are as a rule slow in responding to new discoveries and improved methods and they often fail to properly list and supervise their meters and other equipment. Examination of the inspector's reports, at least in our state, reveals the fact that while some municipalities provide good service, the service in a greater proportion of them is, on the whole, on a lower level than is the case of privately-operated plants.

Manuscript of this paper was received January 17, 1916.

"When it comes to rates the situation for municipally-operated utilities is no better. When the Commission first entered upon its duties, it found the state literally streaked with unjust discriminations which were as flagrant in municipally-operated as in privately-operated plants. While these discriminations have now been largely done away with, the task of wiping them out was also fully as great for the former class of plants as for the latter. The same is also true when it comes to establishing and maintaining equitable rates. While the rates charged by the municipally-operated plants are often relatively low, this is not often due to a low cost of production of the service, but largely because in one way or another upkeep and other costs are shifted from the consumer as such to the taxpayer as such."

Practically all public utilities in the cities of the Western Canadian provinces are municipally owned and operated. An investigation into the municipal activities of the cities of this section to determine to what extent the above criticisms in reference to public ownership could be applied to them, should aid materially in presenting new facts in the discussion of public ownership. After a study extending over four years, an inquiry was made during the summer of 1915 into the municipally-owned electric light and power utilities of these cities.

The electric light and power utility was chosen because it was one of the first to be established and is also one with which comparisons can be made with privately owned systems. It has become better organized and established than some of the other civic undertakings and the early mistakes in its management are now apparent. Its organization is also more extensive than later utilities. Hence for the reasons just stated, its production costs and physical equipment would probably show any inefficient or incompetent administration under municipal ownership better than other more recent ventures in civic control. The investigation was intended to cover certain social and economic phases of municipal ownership as well as its technical aspects. Hence the character of the people and their cities will be discussed together with the administration, organization, financing, physical equipment and rates of the municipal electric light and power departments.

Social Considerations

It would be a very difficult matter indeed to differentiate between the people of the various cities under discussion, but as a class they have some distinct characteristics. In the first place the Canadian West is a "young man's country." The residents of the cities generally came west as young men

and have seen the country develop. All are optimistic and boosters of the West in general and of their own locality in particular. They have learned to cooperate in many lines, such as boosting real estate ventures, etc., and this has had a very marked effect on the conduct of municipal affairs. In fact this spirit of cooperation is the real basis of the success of their municipal ownership ventures. The cities that have not developed this spirit to the fullest extent are those that have had troubles with politics and local interference in the administration of their utilities.

The people of these Western cities were the restless and ambitious elements of the United States, Eastern Canada, the British Isles and foreign countries. The British sentiment is very strong and carries with it the imported ideas of municipal ownership. The readiness of the Canadian and American elements to try any new system that appeared reasonable and promising, accounts for the early acceptance of these principles of civic control and operation. Another characteristic that is peculiar to the West is the general lack of class distinctions.

This democratic condition has resulted in a better mutual understanding and a wider range of interests between all members of the community. Political machines are harder to build up under such conditions and there has apparently been less keen competition for positions in civil employ. The fixed compensation in such work appeals less to the average individual than the gambling chances of other classes of business.

Characteristics of the Cities and their Utilities

Manitoba, Alberta and Saskatchewan are primarily agricultural provinces at the present time, although the great natural resources in water power, coal, oil, gas, asphalt and iron will undoubtedly lead to great industrial development in Alberta in the near future. Of late years the urban population of these states has grown faster than that of the country districts. A partial crop failure in 1914 and the war depression brought this unnatural condition very forcibly to the attention of the people and as a result there has since been a steady trend back to the land.

British Columbia on the other hand is a land of high mountains, rolling plateaus and very fertile valleys. Its interests vary from fruit raising, ranching and other agricultural pursuits to lumbering, mining and fishing. Undoubtedly great mineral

wealth will be developed in the future although at present much of the country has not been prospected or opened up. The electrical utilities of the two largest cities, Vancouver and Victoria, are privately owned. Only one of the cities having municipal plants was investigated.

The outbreak of the European war proved a hard blow to Western Canada. Not only have tens of thousands of the best fitted young men gone to the front, but the money in the country has been diverted from local development to war purposes. The closing of the European money markets has cut off for the time being any borrowing for future development. This situation has resulted in a complete tying-up of all industry and commerce. The present financial stringency will, however, be relieved in a measure when the large crops of 1915 are marketed.

Comparatively few manufacturing industries have been established in the West. Those in operation either handle agricultural or sea products, such as in packing plants, flour mills, food product plants, fish canneries, etc., or supply the rural needs by lumber mills, cement plants, brick works and agricultural machinery shops. In the natural gas district around Medicine Hat, metal-working industries such as machine shops, brass foundries, rolling mills and also glass works, have been started and will no doubt expand with the growth of the country.

The cities selected are the larger ones of the Western provinces. These have been characterized by extremely rapid growth within the last fourteen years, as shown by Table I. At the same time they have been exploited by real estate speculators until land values became greatly inflated in 1914. This resulted in a financial collapse just before the war broke out.

An example of this exploitation is to be found in extensions of the municipal street railways which were frequently made under political pressure from the land speculators. Generally such extensions have not paid for themselves and are now a source of considerable loss to the city. Each city council has had full power to undertake such expense and in boom times the people allowed them to do so. It would seem advisable to have some provincial executive board independent of the city's governing body which would have authority to restrain such needless exploitation and to act as a brake on too-confident municipal administrations.

Brief outlines of the characteristics of each of the cities con-

sidered and of the history of their municipal electric plants will be given in the following paragraphs.

Regina is the capital of Saskatchewan and as such will always be a city of importance. Its growth has been more steady than that of other Western cities and it is built up with fewer outlying subdivisions. This consolidated condition makes it an easy city to serve with electric light and power, but a poor city for financially successful street car operation. It has no manufacturing industries of any consequence.

The city first built a power plant in 1904. Additions were made to this old plant from time to time until 1914 when its undesirable location making further extension inadvisable, a new plant was built. This new station will take care of all future growth for many years. The fixed charges on the old

TABLE I.—DATA ON SIZE OF CITIES.

City.	Estimated present population	Population as per 1911 census.	Population as per 1901 census.
Kamloops, B. C.	5,500		
Medicine Hat, Al'ta	9,000	5,603	1,570
Lethbridge, Al'ta	10,000	8,050	2,072
Moose Jaw, Sask	20,000	13,823	1,558
Saskatoon, Sask	25,000	12,004	113
Regina, Sask	40,000	30,213	2,249
Edmonton, Al'ta	50,000	24,900	2,626
Calgary, Al'ta	80,000	43,704	4,392
Winnipeg, Man	200,000	128,157	42,340

and new plants form a considerable item in the cost of electricity. The increased operating economy of the new plant will, however, practically offset the increased fixed charges. This economy will become more appreciable as the plant increases its output.

Saskatoon is the leading city of central Saskatchewan and is the seat of the Provincial University. It is a large distributing center and also has large mills producing food products.

Its first municipal station was started in 1908. On account of the city's growth, this was superseded in 1911 by a new plant. But in this plant too, proper provision was not made for the rapid growth of the city and as a result it has been necessary to replace reciprocating engines by steam turbines of

greater capacity. The present plant is well situated and is now equipped for economical operation, but is somewhat handicapped by extremely high coal costs due to freight rates on the long haul from the Alberta mines.

Moose Jaw has always been a railway town, the Canadian Pacific Railway having maintained large car shops at this point for many years. Its other industries include flour mills, a packing plant, etc.

The city undertook the production of electric power in 1904. The power plant was burnt down about 1912 and was a total loss. Afterwards a new plant was built on the same site. This additional expenditure has serious effects on the city's finances and as a result the new plant was not fully equipped when war broke out. The plant is well laid out and when finished should give good service.

These Saskatchewan cities are all in prairie country and have no nearby available supplies of water power, cheap high-grade coal, or natural gas. A private corporation has recently proposed to pipe natural gas to them from the Alberta gas fields. The city of Regina has made an agreement with this company to buy the gas at wholesale at the city limits and will sell it to customers from a municipally-owned and operated distribution system, which the city will install. Meanwhile all power must be derived from coal brought either from Alberta or from the Great Lakes. It therefore seems improbable that they will become great industrial centers in the near future. Their further growth will depend then on their natural development as distributing centers.

With neither water power or cheap coal at hand, it is probable that few attempts will be made to transfer their public utility power loads to private corporations. Quite recently, however, a suggestion was made to supply them with electric power derived from low-grade lignite coals which occur in large quantities in the southern section of the province and are an extension of the North Dakota fields. Even in case such a project is successfully completed, it is probable that the cities would buy the power at wholesale rates at a local terminal station and continue as before to sell it to customers from their own distribution system, retaining their present municipal plants as reserves.

In contrast to those of Saskatchewan, the cities of Alberta have large coal fields near at hand, while Calgary has also cheap

water-power. It is therefore natural to expect considerable industrial development in these cities in the near future.

Medicine Hat, besides having coal deposits practically under the city, is located in the center of the most extensive of the Alberta natural gas fields. It is thus assured an ample supply of cheap fuel. Although built in the rolling, dry belt of Alberta, the presence of the natural gas has resulted in a more rapid industrial growth in this city and surrounding towns than in any other city in the West. Reference has already been made to several of these plants.

Natural gas is used throughout the city for all domestic purposes such as heating, cooking and largely for lighting as well. It is also used for street lighting. The success of a municipal electrical plant under such conditions was therefore doubtful and it was not decided to build such a plant until 1911. At first a gas engine plant was installed, but in November 1913 a new steam turbine plant was put in operation and took the load formerly carried by the gas engines. This change was made largely on account of the high first costs and repair charges on the gas engines, which resulted in high power costs. A very simple plant was installed without superheaters or economizers, for the gas used under the boilers was supplied by the city's own wells at a very low cost.

The demand for power for industrial purposes developed very rapidly until war broke out. It is probable that this demand will increase again with the re-adjustment of conditions after the war.

Lethbridge in Southwestern Alberta is the center of an extensive colliery district and serves as a distributing point for the surrounding towns. Although well supplied with coal and natural gas it has not developed any industries except those connected with mining. All the collieries have their own plants.

The city bought out the electrical plant of a private company in 1908. This plant was uneconomical in operation and poorly located. Work was started at once on a new plant. The old station burnt down in December 1909 just before the new plant was complete. The location of the new station, while favorable for operation, was such that construction costs were excessive and in consequence the plant has high fixed charges.

The municipality owns and operates its own coal mine on leased land adjacent to the plant. On this account it has the cheapest coal supply of any city in the West.

Edmonton is the capital of the Province of Alberta and is the

location of the new Provincial University. It embraces about 56 square miles within its boundaries as a result of real estate exploitation. Its industrial works consist principally of two packing houses, lumber mills, flour mills, brick yards, etc. It is expected that the great undeveloped sections of Northern Alberta will contribute largely to the future prosperity of this city as it is the natural outlet for the whole north country.

There are seams of lignite coal under the city itself, while higher grade coal occurs in great quantities to the west of the city. Several undeveloped water power sites in the neighboring country are available for power development.

Edmonton's municipal power plants have had interesting histories. The first electric station and pumping plant was built on the banks of the North Saskatchewan River apparently with no consideration of future developments. This plant soon reached its maximum capacity and a producer gas power plant was installed in an adjoining building to furnish additional electric power. A separate pumping station was next built a short distance from the old plant. It was provided with its own boilers and with a vertical reciprocating pumping engine placed in a pit. In a few years another steam power plant was erected beside the producer gas building with reciprocating engines and hand-fired boilers. Later this was extended and steam turbines and boilers with mechanical stokers were installed, several steam engines were scrapped, and the original station definitely abandoned. In the meantime the pumping plant was enlarged and the vertical reciprocating pumping unit was scrapped in favor of centrifugal pumps. At present the steam required by the pumping engines is supplied from the main boiler plant through a tunnel and the pumping plant boilers are permanently closed down. When Edmonton absorbed the town of Strathcona on the opposite side of the river, its electric plant and pumping station were also taken over. These operated non-condensing and were therefore uneconomical in operation. The Strathcona plant was closed up as soon as the water and electrical services could be assumed by the Edmonton station. It can thus be seen that the present municipal plant is somewhat of a makeshift. Contracts were let over a year ago for the construction of a complete new power house. But the war made necessary the postponement of these contracts. At the time of this investigation the city was considering the purchase of power from private corporations. Some of these were hydroelectric

proposals, others were from coal companies who proposed to generate power at their mines and transmit it to the city.

Calgary in Central Alberta is the leading city of the middle west. It appears to have sustained less crippling of business during the war depression than any of the other cities. On account of cheap water power, available nearby coal fields and its supply of natural gas, it is developing into an important industrial center. Among its principal industries are the big Ogden car shops of the Canadian Pacific Railway, a cement mill, a packing plant, soap works, lumber mills, flour and food product mills, etc.

Calgary started its first municipal plant in 1905 and kept adding to it until 1911 when a new plant, in a more favorable location, was put in service. About the same time a private corporation, the Calgary Power Co., which now has 31,500 h.p. available in its two hydroelectric stations, entered into a contract with the city to supply it with power up to 8000 h.p. But on account of low water at the time of the winter peak loads, the city has had to maintain its plant at a capacity capable of carrying the full load in an emergency. The fixed charges on this steam plant now form a considerable proportion of the cost of power.

A private corporation, the Eau Claire & Bow River Lumber Company, serves customers in the central part of the city with electricity partly derived from water power and partly from a steam plant. This company had a franchise previous to the establishment of the municipal plant. Another private company has a franchise to supply natural gas for domestic purposes at a cost of 35 cents per 1000 cubic feet. Much domestic lighting is done with gas. Hence the load on the municipal plant is not so large as would be the case if it had a monopoly of the lighting business as in other cities.

Half of the boilers in the municipal plant are fired by gas of 1000 B.t.u. per cubic foot and costing 15 cents per 1000 cubic feet. The others burn coal. The plant is well designed and well equipped and when in continuous operation produces very cheap power.

At present an agreement for one year is in force between the city and the Calgary Power Company whereby the latter supplies the full city demands for power at a low figure and has the use of the municipal steam plant for emergencies. The Calgary Power Co. pays all operating and maintenance costs

at the municipal plant, which is still handled by the regular city operating staff. The company does not, however, pay any of the plant's fixed charges.

The steam plant is arranged for ample future development. At the present time, several additional hydroelectric proposals are receiving consideration. With an abundant supply of cheap water power further additions to the steam plant may become unnecessary.

Winnipeg is the largest city in all Western Canada, and being the outlet to the east of all the western railroads, it has great future possibilities.

A private corporation, the Winnipeg Street Railway Co., had a franchise to furnish electric power and operate street railways very early in the history of the city. Up to 1907 this company charged 20 cents per kw-hr. for lighting. In that year it put into operation its hydroelectric plant at Lac du Bonnet and reduced the rate to 10 cents per kw-hr.

In the meantime the citizens recognized that only by having a supply of very cheap power could they hope to see Winnipeg become an industrial center and they voted money in 1906 for building a municipal hydroelectric plant which was completed and put in operation in 1911. The rates quoted to its customers were much below the former prices of the railway company. In 1914 the municipal plant at Point du Bois had a generating capacity of 22,500 h.p. which has since been increased to 50,000 h.p. The total power available at this plant is 100,000 h.p. The design and operation of this plant have received much attention in the technical press and will not be described here.

Kamloops was the only city in which enquiries were made in British Columbia. It is located at the junction of the North and South Thompson Rivers in the central section of the province. Kamloops is a divisional point on two transcontinental railroads. The surrounding country is a rich agricultural and fruit district. Some mining is carried on in adjacent sections and it is probable that this industry will increase in importance as the country develops.

The city's first municipal plant was built about 1907. Owing to the rapid growth of Kamloops this plant proved inadequate and a new municipal electric plant of 1200 kw. capacity was built in 1912 together with a new pumping plant on a site east of the city where an excellent water supply was available from

the South Thompson River. But owing to the high price of fuel, it was decided to develop a hydroelectric site at Barriere about 18 miles north of the city. Unexpected difficulties were encountered in the construction of this plant and it was not put in service till the beginning of 1915. It has a capacity of 1500 kw. which can be increased later as the load builds up. The transmission line to the city carries 44,000 volts with a step-down transformer station at the steam plant. The cost of this hydroelectric system far exceeded the original estimates and the steam plant is still held as a relay, consequently the electric service of the city has to bear very high fixed charges due to these two plants.

Other utilities owned by the various cities and some general information regarding them is given in Table II. Besides those undertakings given in the table, practically all maintain municipal hospitals.

Organization of Utilities

The organization of the municipal governments varies somewhat in the different cities. However, it is generally the practise to have three commissioners in charge respectively of Finance, Utilities, and Public Works and Welfare.

In some cases these are elected by the people and in other cases are appointed by the city's common council. At Lethbridge the public utility commissioner acts as superintendent of the electric light and power department and of the street railway system. Generally, however, a superintendent is provided for each utility. In the case of Calgary and Edmonton, the city's electrical engineer takes charge of the distribution of the current from the plant's switchboard.

In general the superintendents of these municipal utilities are capable men and are exerting as much energy to secure economical results as if they were employed by private corporations. Most of them have held their positions for a considerable length of time and have virtually developed and built up their utilities. These executives are not likely to be subject in municipal service to as much pressure and driving from high officials as in the case of superintendents with private concerns. Hence their success is largely a measure of their own personal initiative.

All the provinces have very stringent boiler inspection and engineer's licensing laws, and as a result, the operating engi-

TABLE II.—DATA ON PUBLIC UTILITIES.

City	Electric light and power	Electric street railway	Water works	Sewage	Gas	Other utilities	Source of water supply
Kamloops, B. C....	Municipal	None	Municipal	Municipal	None	....	South Thompson R.
Medecine Hat.....	Municipal	None	Municipal	Municipal	Municipal	....	South Saskatchewan R
Lethbridge.........	Municipal	Municipal	Municipal	Municipal	Private Corporation	Coal Mine	Belly River
Moose Jaw.........	Municipal	Private Corporation	Municipal	Municipal	None	Cemetery	Local Creek
Saskatoon..........	Municipal	Municipal	Municipal	Municipal	None	Cemetery	South Saskatchewan R.
Regina............	Municipal	Municipal	Municipal	Municipal	None	Stock Yards	Lake Wascawa
Edmonton.........	Municipal	Municipal	Municipal	Municipal	None	....	North Saskatchewan R.
Calgary............	Municipal	Municipal	Municipal	Municipal	Private Corporation	....	Elbow River
Winnipeg..........	Municipal	Private Corporation	Municipal	Municipal	Private Corporation	....	Hydro Plant Winnipeg River.

neers in the various plants are all high grade men. The firemen, as a rule, are men working up for a license and consequently take an interest in their plant and in their work. Such operating forces should be able to give the superintendents valuable aid in obtaining economical results.

In only one case did there seem at present to be any politics in the organization of the plant. This city, however, has had a long record of political and civic-council interference with the operation of its utilities, greatly to their detriment. Another city is said to have had similar experience in the past but seems to have overcome these evils at the present time. Considerable criticism was heard in Edmonton in regard to the operation of the city's municipal street railway system. Its employees had formed a union and were said to dominate the management of the system through their political influence. An attempt was being made at the time of this investigation to drag the municipal street railway system of Calgary into politics. This utility has up to the present time been the most successful civic tramway in the West and holds a record for good service and competent management.

No civil service laws are in force other than the necessary licensing of engineers. The superintendent engages and discharges the men under him and generally promotes his own men as openings occur and the men have the necessary legal and administrative qualifications.

It has been urged against municipal ownership that more men are employed than would be the case in private plants. In those cities where politicians are said to have interfered with the utilities there seemed to be some evidence of an excess of men, and a laxity of discipline. But in the other cities the plants appeared to have the minimum number of men necessary to properly carry on operation. The new municipal plant at Regina is a striking example of careful layout and operation to reduce labor to a minimum, as very few men are needed to run this station.

Another interesting fact is that almost all plant employees are under middle age. One may partly account for this condition by the use of recently developed machinery to which the older men have not adapted themselves.

A very necessary factor for obtaining efficiency in planning and operating a utility, is continuity of management. If a spoils system exists in municipal politics one cannot expect the

city's public utilities to be either well managed or suitably equipped. The spoils system as generally understood does not seem to exist in any of these cities. On the other hand Edmonton has suffered severely from too frequent changes in the management of its utilities. The new man coming in was usually forced to complete work unfinished by his predecessor and with which often he was not fully in sympathy. Then he also was liable to removal before he had his plans for improvement fully carried out. This has resulted in the heterogeneous assortment of equipment and the odd station lay-out already described.

Power Plants and Equipment

All of these cities as shown in Table I have grown very rapidly in a very short period. This rate of growth could hardly be foreseen in any particular city for other towns equally favored did not develop so rapidly. Hence much of the earlier plant equipment due to small size and poor operating economy has become obsolete. There has, therefore, been in each city a rebuilding of old plants and the construction of new plants as noted in preceding paragraphs.

The power plant buildings in most cities are of the usual construction with steel framing and brick walls with the usual arrangements for lighting, ventilation and traveling cranes. Regina's plant, however, is an exception. Here the city went to considerable expense to make its new plant conform with the general plan of buildings to be erected on the adjoining Governmental reserve. Saskatoon's plant also shows a considerable amount of architectural taste.

Table III gives some general data on the equipment of the various plants. All have standard B. & W. water tube boilers equipped with superheaters except in the cases of Medicine Hat and Kamloops. Induced draft fan equipments are used everywhere except in Kamloops. At Regina forced draft fans are also used in connection with the mechanical stokers. At Edmonton an "évasé" or Venturi form of induced draft stack is used, where a 20-h.p. motor drives the fan necessary to serve 2000 b.h.p. The Kamloops plant has a six-ft. concrete chimney 185 ft. high.

A question arises as to whether a chimney and natural draft would not be more economical in some cases. At Regina on account of the proximity of the Parliament Buildings and Park, a chimney was not permitted. In several cases the

TABLE III.—STEAM PLANT EQUIPMENT.

City	Generator capacity	Boiler capacity	Economizers	Main engine equipment.
Kamloops	1,200 kw.	4 Boilers 1000 h. p.	None	2— 600 kw. Curtis Turbines.
Medecine Hat	3,000 kw.	4 Boilers 1600 h. p.	None	2— 750 kw. Curtis-Rateau Turbines. 1—1500 kw. Curtis-Parsons Turbine.
Lethbridge	2,300 kw. 2 Phase	8 Boilers 2260 h. p.	1-Green 1-Sturtevant	1— 300 kw. Compound H. S. Engine. 1— 500 kw. Triple Expansion H. S. Engine. 1—1500 kw. Curtis-Parsons Turbine.
Moose Jaw	3,000 kw.	8 Boilers 2600 h. p.	Sturtevant	1— 500 kw. Curtis Turbine. 1—1000 kw. Curtis Turbine. 1—1500 kw. Curtis-Parsons Turbine.
Saskatoon	5,950 kw. 2 Phase	8 Boilers 4000 h. p.	Green	1— 750 kw. Compound Corliss Engine. 1—2000 kw. Parsons Turbine. 1—3250 kw. Parsons Turbine.
Regina	7,600 kw.	Old Plant 4 Boilers 1600 h. p. New Plant 8 Boilers 2600 h. p.	Sturtevant	1— 300 kw. Corliss Engine. 2— 400 kw. D. C. Engine Units. 1— 500 kw. L. P. Parsons Turbine. 2—1500 kw. Curtis-Parsons Turbines. 1—3000 kw. Curtis-Parsons Turbine.
Edmonton	10,250 kw.	16 Boilers 7000 h. p.	None	2— 400 kw. D. C. Compound Engines. 1— 750 kw. D. C. Triple Expansion Engine. 1— 700 kw. Producer Gas Engine. 1—1000 kw. Compound Corliss Engine. 1—1000 kw. Parsons Turbine. 1—2000 kw. Curtis-Parsons Turbine. 1—4000 kw. Curtis-Parsons Turbine.
Calgary	11,350 kw.	16 Boilers 5430 h. p.	None	1— 600 kw. Triple Expansion Engine. 1— 500 kw. Triple Expansion Engine. 1— 750 kw. Compound Corliss Engine. 1—2000 kw. Parsons Turbine. 1—2500 kw. Curtis-Rateau Turbine. 1—5000 kw. Parsons Turbine.

power plants are located beside rivers in the bottom lands under the bluffs and it was feared this might prevent a chimney from providing draft unless of excessive height. In general, however, it is claimed that radial brick and concrete chimneys were too expensive to commercially compete with the induced draft plants.

Underfeed stokers are giving good satisfaction at Regina. Natural gas is burned in Gwynne burners in Medecine Hat's plant and in part of the Calgary station. Chain grate stokers are in use in all other plants except Kamloops. Hand fired grates were installed at Kamloops where wooden slabs from the lumber mills are burned part of the time as fuel.

Coal and ashes are almost universally handled by bucket conveyers. The coal is stored in elevated bins above the firing aisle. The ashes are elevated into storage bins convenient for loading railroad cars. Most plants are now provided with equipment for analyzing and testing their coal. Several practically buy coal on the heat unit basis. Economizers are used where coal is expensive and therefore when full utilization of heat is of first importance.

In the newest installations there is a decided tendency towards motor drives for all auxiliaries.

Admiralty-type feed pumps are installed in many plants though the simple turbine-driven centrifugal boiler feed pumps have been used in two cases.

The waters of Western Canada generally contain scale forming salts which make them unsuitable for boiler feed. However, there is no uniformity of treatment of the feed water. Some plants soften it while others use boiler compounds. All use feed water heaters. The condensate from the surface condensers is returned to the boilers in every station.

The adoption and use of instruments to increase boiler room economy is universal. Coal as a rule is automatically weighed and recorded. Gas burned under boilers is metered. The boiler feed water is generally measured by V-notch recorders which have universally given good satisfaction. Venturi meters are employed in some plants. CO_2 recorders are in use in almost all plants. Steam flow meters have been installed in a few cases. Many plants are equipped for making complete tests and these are carried out at regular intervals either to determine the best coal to use, or to learn the most economical methods of operation.

The older generating equipment consisted of steam engines, usually of the vertical high speed or Corliss types. Steam turbines have been provided in all recent installations. It is interesting to note in Table III the predominance of Parsons and Curtis-Parsons units. The number of British machines is also a striking feature. Recent purchases indicate an increasing preference for European machinery. The preferential tariff to the British Isles has something to do with this condition, though the most recent order—a 6000-kw. turbo-generator for Edmonton, was taken by a Swiss company.

Usually the condensers are supplied by the party that furnishes the main turbine. These are all of the surface type and give little trouble from tube failures with the cooling water used. All foreign condensers are provided with vacuum augmentors of various types and are usually supplied with three-throw motor-driven air pumps, which maintain high vacuum.

In electrical machinery, the use of European equipment is even more noticeable than in the case of the engines and turbines. The switchboards with one exception are of American manufacture and have been built according to modern practise.

All the larger plants are provided with some machine tools to enable them to make their own repairs. Fine toilet rooms, wash rooms and lockers have been provided in many stations for the men.

In Saskatoon, on the initiative of the superintendent, a society for mutual improvement along technical lines was formed among the utility's employees. Apparently this has not been attempted in other places and outside of local engineering societies there seems to be no organized effort to educate the men in technical subjects.

The Winnipeg plant, being hydroelectric, is not included in the preceding general statements. The plant is built on the Winnipeg River, 77 miles from the city. The power is carried into town over a high-tension transmission system. During construction it was necessary to build an electric tramway to the plant to convey the needed materials and machinery. This is still retained and operated by the city.

On the basis of these facts it may be stated that as a whole the municipal power plants of these cities are up-to-date in the matter of physical equipment, though often retaining some of the older units as reserve. They are also provided with competent staff and modern instruments to ensure efficient operation and low unit production costs.

Distribution Systems

In considering distribution systems, it must be remembered that the cities are new and are scattered over large areas. This in a measure simplified wiring problems although provisions for future growth have made necessary many underloaded circuits and transformers. In those cities where the total output is metered the distribution losses run from ten to eighteen per cent of the current generated.

The consulting engineers who were employed in laying out the first plants of several of these cities insisted on two-phase alternating-current systems. Most plants have been entirely changed over to three-phase, but at least two cities are still operating with two-phase machinery and distribution systems involving unnecessarily high first costs and maintenance charges.

Distribution systems are generally at 2300 volts except in some cases where 6600 volts is carried to substations. The use of 2300-volt motors for power service is increasing. The starting devices used with these motors are more complicated than with lower voltages, but being without transformers, the net efficiency of the service is higher.

In two cities the distribution system is in charge of an electrical engineer and is independent of the power plant superintendent. In general, however, the whole electric light and power utility is under the supervision of one man and this seems to be the more desirable and more efficient condition.

Cost and Financing of Utilities

All of these utilities are financed by loans on municipal debentures whose terms vary from 20 to 35 years and longer, and bearing interest at rates of 4 to 6 per cent. Most of these were marketed in Great Britain, though a few were placed in Eastern Canada and in the United States. The expansion of Western Canada was so rapid before the war, that fears were expressed in financial circles that these cities were exceeding their ability to meet these obligations. Hence recent debenture issues have had to bear higher interest than earlier ones on this account. The war, however, has closed all money markets and the West, being without funds to carry on development, has felt the resulting depression much more keenly than the East.

The municipalities provide for the retirement of these de-

bentures by the maintenance of sinking funds. Interest and sinking fund charges must be met out of the current revenue of the utility and in general, rates are adjusted to produce these funds together with a small surplus for emergencies.

An attempt has been made in Tables IV and V to summarize the financial statements for the year 1914 of the various utilities discussed. In every case possible the auditor's statements were used as a basis for the analysis. The kilowatt rating of the plants is that of the machinery available for service. The plant value per kilowatt capacity in Table V seems high in several cases. This usually covers obsolete machinery still carried on the books, together with the costs of errors and mistakes made in building up the plant from a small station. The power output of the plant in kilowatt-hours was used as the basis for the figures in Table V which shows all costs on a kilowatt-hour basis. Table V also includes average figures in nineteen Massachusetts steam power plants for 1914, based on the returns of the companies to the Board of Gas and Electric Light Commissioners of that state.

In connection with the high first costs of the distribution systems and the yearly distribution costs, attention is drawn to the fact that these cities have grown up with homes scattered over large areas. The municipal utility has had to supply all reasonable demands for light and power even in the most outlying districts. This has resulted in high pole and line expense and correspondingly high upkeep charges.

The capital cost for the hydroelectric plant at Kamloops has been so great that its fixed charges will nearly equal the former cost of fuel in the steam plant. But the labor cost will be less than before. Hence the net cost of power will not be appreciably decreased by the use of hydroelectric power unless the load factor of the plant can be greatly increased. Efforts are being made to secure additional mining and irrigation loads.

It has been said that the electrical utility at Medicine Hat does not pay enough for the gas that it consumes and that if it were charged the same rates as other consumers, the surplus would be wiped out and higher rates might even be necessary.

In the Moose Jaw statement in Table IV, a deduction of $9,012.00 is made from the total cost. This covers the charges for operating the city pumping station which is connected with the electric plant and operated by the same force. Hence for purposes of comparison in Table V, this cost was deducted

TABLE IV.—SUMMARY FROM 1914 FINANCIAL STATEMENTS.

	Kamloops	Medicine Hat	Lethbridge	Moose Jaw	Saskatoon	Regina	Edmonton	Calgary	Winnipeg
Present population	5500	9000	10,000	20,000	25,000	40,000	50,000	80,000	200,000
Rated kw. of plant	2700	3000	2300	3,000	5,950	7,600	10,250	11,350	30,000
Total debenture issue	$506,500.00	$430,000.00	$689,665.73	$707,853.39	$1,047,665.10	$1,486,333.34	$2,830,190.99	$2,029,202.28	$7,412,000.00
Value of plant	$502,693.49	$368,142.89	$456,370.78	$354,071.80	$570,000.00	$704,464.20	$1,955,091.06	$976,287.09	$3,962,144.49
Value of distributing system			$139,757.37	$190,446.68	$430,000.00	$625,031.61	$745,985.94	$1,188,921.37	$2,904,779.09
Kw-hours generated	2,628,100	3,050,070	3,415,000	3,739,990	8,873,642	9,315,355	21,027,089	31,391,596	62,493,162
Kw-hours metered	2,338,912	......	......	3,031,246	7,966,920	8,223,895	......	......	......
Net revenue	$84,692.89	$49,251.08	$110,898.53	$179,428.26	$340,628.08	$326,435.73	$767,870.71	$670,512.24	$976,347.50
Cost of coal	$4.90	(Natural Gas)	$1.20	$3.40	$6.66	$5.40	$3.22	(Gas and Water Power)	(Water Power)
Operating Costs									
Fuel	$35,271.92	$1,000.00	$12,562.55	$53,624.12	$121,296.68	$131,565.43	$165,238.86	$48,735.17	......
Wages	13,951.78	12,721.98	14,953.84	21,531.98	28,972.22	41,023.17	78,619.25	32,056.20	$41,330.32
Water	......		720.00	1,698.25	2,605.71	824.48	1,538.40	5,048.00	......
Oil, waste, supplies etc.	1,094.01		2,452.76	5,257.74	3,950.73	5,509.54	7,272.25		8,538.79
Repairs and maintenance	98.26		7,627.23		11,541.90	10,549.25	56,919.81	11,732.74	29,621.02
Distribution Costs									
Wages	1,804.17	3,350.87	1,357.05	9,941.24	17,595.59	4,703.30	34,739.23	80,648.89	8,552.96
Repairs and maintenance			7,314.77	11,450.95		14,594.73			36,786.47
Miscellaneous	......	135.41	......	3,183.94	......	4,425.93	7,403.57	166,075.84	109,532.18
Overhead Costs									
Salaries	4,012.95	3,593.25	5,529.44	2,475.00	19,424.56	14,482.53	41,722.66	71,379.48	55,290.00
Office expenses	375.97		2,767.85	8,218.34			6,208.99		34,041.16
Insurance	603.47	......	575.92	1,001.14		2,324.70	1,949.45	3,224.52	182.20
Taxes	......	......	8,114.67	1,028.95	......	......	4,824.68	8,675.24	4,007.05
Employers liability insurance	......	......	514.65	1,578.34	......	......	......	......	......
Fixed Charges									
Interest	10,225.20	14,821.95	30,071.15	29,704.47	45,690.22	63,107.93	175,063.84	93,339.97	305,526.11
Sinking funds	4,147.80	13,004.26	16,069.72	......	20,983.77			35,612.94	......
Depreciation	......	......	......	24,865.13	29,967.76	19,370.65	106,606.82	36,125.29	264,254.52
Total Cost				175,559.59		311,481.64			
Less deductions				9,012.00		7,001.62			
Net cost	71,585.53	48,627.72	110,631.60	166,547.59	302,029.14	304,480.02	688,107.81	592,654.28	897,662.78
Surplus	13,107.36	623.36	266.93	12,880.77	38,598.94	21,955.71	79,762.90	77,857.96	78,684.72

TABLE V.—COSTS PER KW-HOUR GENERATED, 1914.

	Kamloops	Medicine Hat	Lethbridge	Moose Jaw	Saskatoon	Regina	Edmonton	Calgary	Winnipeg	Average of 19 Mass. Cities.
Present population	5,500	9,000	10,000	20,000	25,000	40,000	50,000	80,000	200,000	66,700
Rated kw. of plant	2,700	3,000	2,300	3,000	5,950	7,600	10,250	11,350	30,000	7,530
Kw-hours, generated	2,628,100	3,050,700	3,415,000	3,739,990	9,716,142	9,315,355	21,927,089	31,391,596	62,493,162	11,010,000
Cost of coal	$4.90	(Natural Gas)	$1.20	$3.40	$6.66	$5.40	$3.22	(Gas & Water Power)	(Water Power)	$3.65
Plant cost per kw. capacity	187.59	122.71	198.42	118.02	95.80	92.70	190.75	86.01	132.07	....
Distribution system cost per kw			60.76	63.48	72.27	82.25	72.80	104.75	96.82	....
Net Revenue per kw-hour	3.222c.	1.612c.	3.247c.	4.797c.	3.838c.	3.504c.	3.504c.	2.136c.	1.562c.	....
Operating Costs										
Fuel	1.342c.	0.033c.	0.369c.	1.298c.	1.367c.	1.412c.	0.754c.	....	....	0.570
Wages	0.531	0.417	0.438	0.527	0.326	0.440	0.358	....	0.066	0.216
Water	....		0.021	0.045	0.029	0.009	0.007	....	....	0.022
Oil, waste and supplies	0.041		0.071	0.140	0.045	0.046	0.033	....	0.014	0.008
Repairs and maintenance	0.004		0.223		0.130	0.087	0.260	....	0.047	0.092
Total Operating Cost	1.918	0.450	1.122	2.010	1.897	1.994	1.412	....	0.127	0.908
Distribution Costs										
Wages	0.069	0.109	0.040	0.266	0.199	0.051	0.158	....	0.014	0.198
Repairs and maintenance			0.214	0.306		0.121		....	0.059	0.225
Miscellaneous	....	0.004	....	0.085	....	0.047	0.034	....	0.175	0.147
Overhead Costs										
Salaries	0.153	0.117	0.162	0.066	0.219	0.156	0.191	....	0.088	0.344
Office expenses	0.014		0.081	0.226			0.028	....	0.055	
Insurance	0.023	....	0.017	0.027	....	0.025	0.009	....	0.000	....
Taxes	....	....	0.237	0.027	....	....	0.022	....	0.006	0.314
Employers' liability insurance	....	....	0.015	0.042	....	....	....		....	....
Production Cost	2.177	0.680	1.888	3.055	2.315	2.394	1.854	1.362	0.524	2.136
Fixed Charges.										
Interest	0.389	0.486	0.881	0.763	0.515	0.666	0.798	0.297	0.489	....
Sinking funds	0.158	0.426	0.470	....	0.236			0.113	....	....
Depreciation	....	....	....	0.635	0.337	0.208	0.486	0.115	0.423	....
Net Cost	2.724	1.592	3.239	4.453	3.403	3.268	3.138	1.887	1.436	....
Surplus	0.498	0.020	0.008	0.344	0.435	0.236	0.364	0.247	0.126	....

proportionately from the operating costs and the overhead costs. The Moose Jaw plant was partly under construction in 1914, which accounts for a portion of its high production costs.

The deductions in the cost of Regina in Table IV represent the value of extra stock on hand in the store rooms at the end of the year. Hence in order to obtain the values in Table V, this was deducted proportionately from the costs of oil waste, etc., from repairs and maintenance of plant and from repairs and maintenance of the distribution system.

Regina was not using its new power plant during all of 1914. Its economical operation ought to make material changes in the power costs of the year 1915.

At Edmonton the Power Plant department has control of the generation of electricity and the pumping of water. It delivers the electricity at its main switchboards or at the direct current switchboards of its substations either to the street railway or to the electric light and power department which is a separate organization. The report of the superintendent of the power plant showed the operating costs of the steam, gas, water and filtration departments but did not distribute the overhead charges between these subdivisions.

In Table IV the interdepartmental charges were first distributed proportionately among the different items in the summary. Then the overhead charges were distributed on the basis of the total operating costs of the electrical and water plants. This allotted 75 per cent of the overhead charges to the electrical plant and 25 per cent to the water pumping and filtration plants. The latter charge amounted to $10,082.99.

A further analysis of the statements showed a deficit in the water pumping and filtration departments between total revenue and operating costs of $1,119.98. Both this charge and the preceding one of $10,082.99 had evidently been made up out of the revenue of the electrical departments and in Table IV are therefore included in its surplus since the water department operated at a loss.

In addition, the city council in By-law No. 526 set aside the sum of $12,481.26 out of the surplus of the power plant. For the purpose of this analysis this sum is still treated as surplus for the electrical department.

Finally, the statement of the power plant department showed a net surplus over all charges, including the reserve just discussed, as shown by its profit and loss account for 1914, to the

amount of $828.33. This also was evidently earned entirely by the electrical department. The true net surplus for the year was therefore $24,512.92.

The electric light and power department of Edmonton has charge of the distribution and sale of its electricity to private consumers. It is an entirely distinct and separate organization from the power plant department and keeps its own sets of accounts. However in these accounts the selling price of the power plant department for electricity is the cost price to the electric light and power department. For the purposes of this discussion, it seemed advisable to combine the statements of the two departments and this was done in Tables IV and V. The electric light and power department showed a net surplus for the year of $55,190.95. Hence the total surplus from the electrical utility was $79,762.90.

The miscellaneous charge for the city of Calgary includes an item for $150,821.63 which was the cost of 26,463.032 kw-hr. purchased from the hydroelectric plants of the Calgary Power Company. This represents an average cost of 0.57 cents per kw-hr. at the city's terminals. Although the city's municipal plant generated the balance of the power used, *i. e.*, 4,928.564 kw-hr., it did not seem fair to make a distribution of costs in Table V on this basis for most of the costs in this plant included "stand-by" charges for keeping the boilers warm and under steam and for having a sufficient labor force on hand in case of emergency demands for power.

The fiscal year for Winnipeg ends April 30th. The figures shown in Table IV and V are for the year ending April 30, 1915, and therefore cover a longer war period than those for the other cities. There may be some difference of opinion regarding the classification of these accounts in Table IV. The figures for wages include the following:

Labor, Hydraulic Plant	$15,392.21
Inspection and Patrolling, Transmission System	6,414.68
Terminal and Substations, Operating Labor	19,523.43
	$41,330.32

The repairs and maintenance costs cover charges similarly distributed. Office expense cost consists of commercial expense of promotion and collection, general office expense, printing and stationery, and war tax. The miscellaneous costs consist of the following:

Tramway to plant, operation and maintenance	$33,795.34
Extraordinary contingencies	18,076.45
Uncollectable accounts	12,000.00
Expenses on consumers' premises and municipal lamps	8,671.80
Undistributed expense	36,988.59
	$109,052.18

Although no fund is set aside for employee's liability insurance, $9,484.60 was paid out in undistributed expense during the year for injuries and damages.

The item "kw-hr. generated" in Tables IV and V for Winnipeg represents the kw-hr. delivered at the terminal substations. It was thought best to use this figure so that the values would be comparable with those of the other cities. The utility's records show the following:

Total kw.-hours generated	70,743,274
" " " delivered at substations	62,493,162
Line and transformation losses	8,250,112
" " " " per cent	11.6

The financial year 1914 was chosen for this analysis of the costs of these plants not only because these reports were the most recent available but also on account of the lack of abnormal conditions of growth during that period. Previous to this year the increases in electrical demands were exceedingly difficult to forecast. A curve showing the growth of electrical demand that is typical of all these Western cities is that for Moose Jaw shown in Fig. 1.

The year 1914 was a poor one financially for these municipal plants. Industrial plants were closed down at the outbreak of war and the utility's power load was thus decreased. This in many cases made retrenchment necessary and all power plant improvements and extensions were suspended. A decrease in load instead of the expected increase, left all plants with excess power capacity. Consequently higher fixed costs and operating costs were the result.

Table V shows very plainly the effects of cheap gas, coal and water power on the cost of electricity in the cases respectively of Medicine Hat, Lethbridge, Calgary and Winnipeg. The two former cities have comparatively small plants which at present are much underloaded and with low load factors. The effect of the high cost of coal is seen very plainly in the costs of the Moose Jaw, Regina and Saskatoon plants. Such utilities

should therefore have the most economical plants and methods available. In fact this consideration has not been neglected, for these plants are all provided with steam turbines, economizers, superheaters, CO_2 recorders and other apparatus to improve operating conditions and to reduce plant costs.

It is scarcely fair to compare the fuel costs of these Western Canadian cities with that of Massachusetts as given in Table V, for in the West lower grades of coal with less heating value and higher ash and moisture contents are generally used. Labor also costs more in the West than in Massachusetts.

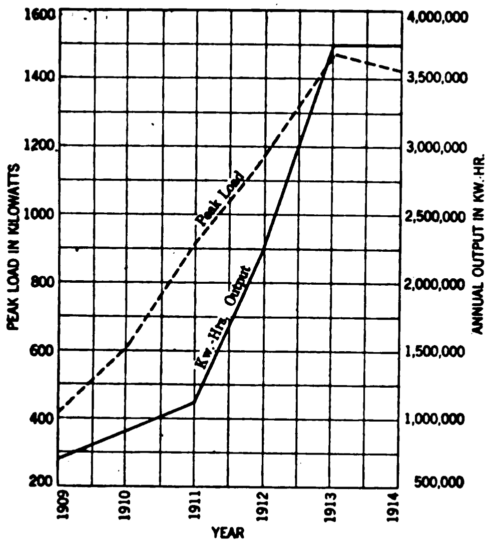

FIG. 1—TOTAL ANNUAL OUTPUT AND PEAK LOAD 1909 TO 1914—MUNICIPAL ELECTRICAL DEPARTMENT, MOOSE JAW, SASK.

TAXATION OF MUNICIPAL UTILITIES

The electrical utilities are taxed as shown in Table IV, in the cities of Lethbridge, Moose Jaw, Edmonton, Calgary and Winnipeg. Only in the case of Lethbridge has the utility been taxed near its full value. In this city, it is held that the utility enjoys the use of the city's streets and alleys for its distribution system and that its business increases with the general improvement of the town. It also receives fire protection and police protection provided by the general taxation of the city. The users of electric light and power thus enjoy privileges at the general expense of the public and should therefore pay in their rates a

proportional tax to cover such extra privileges. In the other cities the taxes are only for a portion of the plant or system. The taxes at Winnipeg probably cover property not within the city limits.

The Lethbridge system is based on the right ideas and is more nearly the correct one. In order to determine the most equitable basis for taxation of such municipal utilities it is necessary to study the classes of service they furnish and the privileges these enjoy.

An analysis of the account of the utilities will show that these may be divided into three general classes.

(A) Municipal services other than revenue-producing utilities. This class includes power and light services in municipal buildings, etc.; street lighting, and in pumping plants for fire purposes and street cleaning use.

(B) Municipal services for revenue-producing utilities such as, street railway power, power to waterworks for domestic supply etc.

(C) Private light and power consumers.

The services rendered by Class A are obviously for the benefit of the whole civic community and there is no justification for taxing the portion of the distribution system providing such service or the proportion of the generating plant necessary to supply such demands.

Class B services provide privileges which while they may be of value to the city as a whole, are enjoyed only by certain portions of its people and are paid for in proportion to the use made of this particular utility. The users of such special service should therefore be expected to pay in their rates a just proportion of the taxation on that part of the plant of the electrical utility provided to serve their needs.

It is obvious that customers in Class C enjoy special privileges in the use of the utility's light and power, and should pay for this privilege as a tax on the proportionate part of the system supplying their demands.

It is thus possible to fairly apportion the taxable and tax-free values of the electrical plant and the land occupied and used by the utility. Such apportionment for taxation purposes should be one of the duties of the Provincial Public Utility Commission.

A question naturally arises regarding the special privileges that made the utility subject to taxation. A survey of the following brief summary of certain features of these plants should

indicate clearly that there is ample justification for subjecting them to taxation.

In the first place the utility occupies land with a plant, of which a portion is used for other than pure civic purposes and produces revenue. It is therefore subject to taxation under all usual plans of assessment and particularly so in those Canadian cities under single-tax. The utility uses the city's streets and alleys for poles and conduits and enjoys fire and police protection as already mentioned. The city's credit was employed in marketing the debentures to build the plant and its credit is still used in purchasing fuel, labor and supplies. Considerable time of the city's executives is devoted to consideration of the utility's special problems and thus a portion of the cost of municipal government is rightly chargeable to the utility. The utility furthermore pays no franchise tax to the city as would be the case in a privately owned system.

Municipal plants under the conditions just enumerated are able to serve private customers at rates below the cost at which they could supply such service themselves and in this way provide these consumers with special privileges which are enjoyed at the expense of the general public when no taxes are paid. It is therefore obvious that taxes should be levied on portions of these utilities and that consumers of classes B and C should pay in their rates, additional charges to meet this taxation which in the end really represents the utility's just share of the general administrative and maintenance expenses of the city as previously outlined.

Referring to Table V, it will be seen that taxes in the case of the Massachusetts cities amount to more than the plant labor costs and form about 15 per cent of the total production cost.

Funds are set aside for employers liability insurance in the case of two cities. Workmen's compensation acts are in force in these provinces. Some of the cities include compensation charges in their miscellaneous expenses, but do not carry insurance for the same.

Debentures Issues and Sinking Funds

Yearly charges for sinking funds have been figured out in most cities and are paid out of revenue, though in Moose Jaw only a depreciation fund is maintained.

Winnipeg also maintains only a depreciation fund which provides for the maintenance and replacement of the plant. Hence,

at the expiration of the life of the bonds (30 years) the plant will still be maintained in first class condition and still in service. The expiring bonds can then be redeemed by a new bond issue.

The investment and use of these sinking funds presents a problem that has received much attention in the West. Some of these funds have been invested in other municipal securities, and in school debentures. Loans have been made on mortgages, while in a few places the money simply draws interest in the banks. In times of depression it would be hard to realize on some of these investments in case this were necessary. There is also the temptation in bad years to fail to set aside the full amount, hoping to make up the deficit at a later date. During depressions it is sometimes impossible to collect all the taxes and in such cases the sinking funds often do not receive their full allotment.

There is necessarily a large element of risk in investments earning high returns and such use of sinking funds should be closely scrutinized. As these funds are public monies, they should only be used in absolutely safe investments.

An innovation in municipal finance has been brought before the public in order to remove these elements of risk incurred with sinking funds. This consists of the substitution of serial debentures for the ordinary long-term debenture with its sinking funds. In the end the cost to the public is the same provided the two bonds can be sold at the same price. In the case of the serial debentures an installment of the principal is paid off each year together with the interest charges on all outstanding bonds for that year. This relieves the municipal councils of the responsibility for sinking fund investment and lifts a considerable burden from their shoulders.

A statement of the case for serial bonds is put very concisely in the following paragraphs from Document 23 of the State of New York's Constitutional Convention.

> The most certain, simple and cheap way to amortize a debt is to pay it off in annual installments. The uncertainties of calculation which have so unfortunately affected our sinking funds in the past are at once eliminated. There is no large fund left in the hands of public officials to be cared for and invested and reinvested for fifty years with all the attendant risk and temptation, and the danger that this power of investment in various local securities may be perverted into a political power is entirely removed. Furthermore, the fact that the same administration that incurs a debt must at once begin within a year to make provisions for its retirement, necessarily and strongly tends towards responsibility and prudence in the contraction of the debt.

It has been maintained that investors prefer long-term securities and in consequence the serial debentures could not be marketed at as favorable prices as under present methods. Several prominent Canadian bankers who were consulted regarding serial bonds, expressed the opinion that there would now be practically no difference in placing the serials at as favorable rates as the long-terms.

One leading American banker pointed out that, at the time of writing, short term bonds commanded better prices than long term securities and that he believed serial bonds could sell fully as well if not better than sinking fund securities.

Document 23 of the New York Constitutional Convention may be quoted with interest on this subject. Referring to the marketability of serial bonds, it is stated:

> After careful investigation, however, your committee is of the opinion that serial bonds are quite as marketable as sinking fund bonds. At a recent sale by the Finance Department of New York City, where a sale of serial bonds was made side by side with sinking fund bonds, the former brought when reduced to terms of equivalent maturity, a better price than the latter, the Comptroller of the city attributing the success to the serial bonds. Inquiry among the large financial houses of New York, Boston, Chacago and Philadelphia has developed practically the unanimous opinion of those authorities that serial bonds are at least as marketable as sinking fund bonds. The system has already been adopted by other States of the Union and is also now in use by many of the cities and smaller subdivisions of this State.

There is a strong temptation in the West to adhere to the sinking fund plan, for often the municipalities are able to invest these funds at rates higher than the interest charges on the debentures and thus they relieve their municipalities of a certain amount of taxation. In spite of the element of risk this is often considered very clever administration.

One further objection to the long term bonds, deserves mention here. Such a bond requires only a comparatively small annual sinking fund charge, which is attractive to an uninformed tax-payer. On the other hand, if an adequate depreciation fund is not set aside to provide replacement of plant at the proper time, owing to the low sinking fund charges, low rates may be quoted at the expense of future consumers. For after the plant has had to be renewed such consumers will not only continue to pay interest and sinking fund charges on the old plant which was worn out by their predecessors and hence is of no benefit to them, but will also have to pay similar charges on debentures

that have to be issued to renew the plant. This is unfair discrimination against future consumers.

Attention has already been called to the long life of many of the debentures. It is certain that the plants which these debentures cover, generally cannot last their full terms. At a certain time it will be worn out and have only scrap value or it may become obsolete, yet the original debentures will still be unredeemed. The more equitable and just system is the modern method of limiting the term of the bonds to the life of the improvement they are to cover. This practise is required by law now in several of the American states.

There seems to be a tendency among accountants and some engineers to over-estimate the life of electrical machinery as used to-day. If one considers for a moment, merely the changes brought about in the last fifteen years by the steam turbine in the power plant and by new lamps and fixtures in the art of illumination, and then if one further determines the number of machines bought so long ago that are still economically serviceable in growing cities, it will become apparent that the estimates of the life of the plant made fifteen years ago have been entirely misleading and in error due to obsolescence either from improvement in the art or from inadequacy in capacity. Apparently such progress is not at an end and present-day machinery will be subject to the same influences. It would be well then for municipal authorities to give careful attention to this phase of the situation when deciding on the probable life of their plant and the debentures to cover the same.

The adoption of serial bonds and the adjustment of their maximum term to the life of the improvement they are intended to cover, will provide an equitable and just method of financing future developments. The question naturally arises whether it would be wise or necessary to readjust the present outstanding securities. It has been suggested that these be exchanged for serial bonds properly adjusted to the life of the improvements they cover. But such could only be accomplished with the consent of the outstanding bondholders. It is probable that this would involve some difficulty on account of the holdings being largely in Europe where any financial innovations would be looked upon with suspicion.

Depreciation and Obsolescence

Probably the most frequent criticism one hears of municipal ownership is that adequate depreciation funds are not set aside.

When renewals become necessary, these must be made either at the expense of the taxpayer instead of the consumer who enjoys the utility, or more debentures must be issued. The larger cities of Western Canada are apparently providing suitable depreciation funds which represent the difference between the life of the plant and that of their debentures, so that the combined funds will replace the plant at the end of its usefulness. Investigation tended to show that the credit for this foresight was largely due to the work of competent auditors rather than to the initiative of the municipal councils.

The smaller cities do not seem to maintain this fund and for that reason their surplus has been declared at the expense of future replacement funds. A study of the situation in each of these cities would undoubtedly lead to the establishment of a depreciation fund even at the expense of slightly increased rates.

The question of obsolete machinery presents many difficulties. Most of the cities have outgrown their first electric plants and these have either been scrapped or are virtually obsolete as reserves. In many cases some of the machines now in use will soon be too small and uneconomical if the city continues to grow. Yet practically the whole value of these former plants is covered by debentures on which the present consumers are paying interest and sinking fund charges. The question arises as to how this obsolescence charge shall be financed.

At Edmonton, the capital account for obsolete machinery in the various plants is excessive, as is evident from the high plant values in Tables IV and V. The former Superintendent, R. H. Parsons, made a commendable effort to wipe out as much of this as possible. In 1912 the power plant was granted $100,000 out of general taxation funds for this purpose. The sum of $170,000 was set aside in 1913 from the power plant revenues for depreciation and obsolescence and in 1914 a sum of $87,817.00 was again set aside for a similar purpose. It was hoped that this obsolescence charge would be totally wiped out in 1915. War conditions, however, made reductions in rates advisable and considerable still remains to be written off the accounts.

In 1913 the auditors recommended a general tax to meet this charge on the basis that the city would be paying for "errors of past years," but this suggestion was not adopted. When this charge for obsolete machinery has been removed either by the retirement of debentures or the replacing of inefficient equipment by modern machinery out of the special depreciation and ob-

solescence funds, it is estimated that the utility can reduce its charges by about 40 per cent.

An appraisal of the plant at Moose Jaw in 1914 showed a sum of $37,700 unaccounted for out of the debenture issue. It will be necessary in the near future to provide a fund to meet this discrepancy and also to provide for some of the fire losses not covered by insurance.

It therefore seems necessary in certain cases to wipe off at once the charges for obsolete machinery either by general taxation or by funds from current revenue secured by increased rates. The latter plan appears to be the more equitable and just of the two, for those enjoying the utility are then paying all its costs.

Charges for Municipal Lighting and Street Railway Power

The revenues of the electric power utilities are dependent to some extent on the rates charged the city for street lighting and the street railway for power. These rates will now be discussed.

Medicine Hat has no electric street lighting or street railway.

The Lethbridge electrical utility charges the street railway department two cents per kilowatt-hour for power. The city lighting equipment belongs to the electrical utility. The city is charged with all repairs and maintenance on this system and pays for power at the net plant cost, including fixed charges on the lighting systems.

Moose Jaw has a street railway owned by a private corporation and operated by Diesel engines. The municipal power plant charges the city the actual cost of maintenance of its lighting system plus a meter rate of two cents per kw-hr. for arc lamps and 2½ cents per kw-hr. for incandescent lamps.

In Saskatoon the street railway is charged 1½ cents per kw-hr. for the direct current it takes from the switchboard of the electrical plant. The city is charged at the rate of $70.00 per year for its arc lamps while tungsten lamps for street lighting and municipal buildings are charged at the regular rates, viz.: eight cents for the first 100 kw-hr., seven cents for the next 50 kw-hr. and six cents for all over 150 kw-hr. per month.

At Regina, the city is charged by the utility, 2¼ cents per kw-hr. plus a service charge of 50 cents per connected kilowatt per month on 428 kw. for street lighting. This does not include repair and maintenance charges. The street railway pays 1¾

cents per kw-hr. for the power used plus a service charge of 50 cents per month per connected kilowatt on 1000 kw. The power is measured on the direct-current terminals leaving the switchboard.

The street railway paid 2 cents per kw-hr. for its power at Edmonton in 1914. For general street lighting the rate is 3.1 cents per kw-hr. plus maintenance and operation cost plus 3½ per cent for departmental charges. The city of Edmonton also pays 5 per cent on capital expenditure for the street lighting system. The city has built a " Whiteway " on Jasper Avenue which is handled differently from the other lighting charges. In this case the charge is 3.1 cents per kw-hr. plus maintenance and operation costs plus 3½ per cent for departmental charges. Two thirds of this gross sum is charged to local improvements as a frontage tax and one third to the city of Edmonton. The city also pays 5 per cent interest on its third of the capital expenditure. The balance of the capital expenditure was charged up to local improvements when the system was built.

Street lighting in Calgary costs a fixed sum per lamp per year. This varies from $65.00 for a magnetite arc lamp to $6.00 for a 16-c. p. incandescent lamp. The street railway pays 1.5 cents per kw-hr. for its power measured on the direct-current wattmeters on the outgoing feeders from the substations.

The street railway at Winnipeg is operated by a private corporation with its own power supply. The city is charged 0.875 cent net per kw-hr. for street lighting and 0.625 cent net per kw-hr. for water pumping, for electrical service from the municipal plant.

There is evidently no uniformity of practise in charging for street lighting and for power used by other utilities. Street lighting usually produces a higher load factor than similar service to private consumers. Water pumping also provides a high load factor and is very desirable service when pumping can be done in off-peak hours. Street railway service on the other hand frequently has no better load factor than other commercial power.

It would therefore seem best to charge for all these services in two parts; first, a demand charge covering the fixed charges of that portion of the plant needed to meet maximum demands, giving proper consideration to when these occur, and second, a meter rate on all current furnished, which rate would consist of operating and distribution costs together with a certain proportional part of the overhead and management charges.

The Disposal of Surplus

In regard to the disposal of surplus, at Kamloops this was carried to a summary account where it balanced the losses incurred in the operation of other utilities.

The profits were small in the case of Medicine Hat and of Lethbridge and were carried over into current revenue. The surplus of Regina and of Saskatoon are carried over into general revenue accounts where they offset in a measure the deficits incurred in the operation of the municipal street railways.

At Moose Jaw the surplus is transferred to the account for municipal street lighting where it balances two-thirds of the cost of this service. This practise is wrong, for street lighting is a public convenience and necessity to the whole community and should therefore be at the expense of the city as a whole. The costs of such service should be included in the general taxes just the same as the cost of sewage disposal, fire and police protection.

Calgary had a total surplus reserve of $154,850.91 set aside by the end of 1914. No purpose has been allotted to the reserve up to the present time. Rates were reduced in 1915 and in consequence it is probable that the surplus for that year will be small.

Edmonton's surplus as already explained consists of the following items:

Power plant's net surplus	$ 828.33
Reserve set aside by By-Law No. 576	12,481.62
Waterworks charges taken out of electric revenue	11,202.97
Surplus in distribution dept	55,190.95
Net Surplus	$79,703.87

Of this amount the waterworks charges should be assumed by the water department by increased rates. The distribution department has now a total surplus reserve of $104,682.47. This has been distributed as follows:

Deficit of Strathcona	$6,554.49
Obsolescence Reserve	15,000.00
Reserve for Underground Construction	83,127.98

It seems hard to justify the use of this surplus for underground construction when the funds are taken from current revenue. This is a case where permanent improvements are being made out of the receipts from current lighting and power rates.

At the beginning of the fiscal year Winnipeg had a deficit of $81,409.89 remaining from a total deficit of $142,273.64 in-

curred during the first two years of operation. The surplus for the current year was applied to this account reducing the net deficit on April 30th, 1915, to $2,725.17, which will probably be wiped out this year and permit lower rates to be quoted to customers.

The variations in practise as set forth in the preceding paragraphs raises the question as to the proper disposal of surplus. The municipalities argue that the utilities are theirs, that they have earned profits which belong therefore to the community, and the city through its governing board can dispose of this surplus as it deems proper.

However, if the situation is analyzed carefully certain facts will be revealed which raise questions as to the equity of the above practise. In the first place these profits accrue out of rates paid by the consumers of light and power and they are therefore paying in their rates more than it is costing the city to provide such service. Suppose such profits are used, as is frequently the case, to make good a deficit in another department, say in the water department, then the consumers of water are paying rates that are lower than the city's gross cost for supplying water. One is then confronted with this situation ,that the electric light users pay a portion of the cost of the water consumer's service. The injustice of this condition is at once apparent. The same reasoning applies in regard to balancing street railway deficits by surplus funds.

On the other hand if the surplus is carried to a general revenue account, and is used to defray the current expenditures of the city or to meet specific civic costs, such as street lighting, it virtually takes the place of additional taxes. Then the electrical consumers are paying a portion of the city's general taxes in addition to the cost of supplying them with power and light. This is neither fair nor just if the utility has already paid taxes on its valuation. If it has not been taxed, then there is a considerable measure of justification for this practise.

Reference has already been made to the practise at Edmonton of utilizing the surplus for permanent improvements. In general when such funds are used either to replace old equipment, to extend the utility or to make permanent improvements in the system, the benefits of such will be enjoyed by future consumers extending over a period of years. They alone should bear the costs of such improvements and it is therefore unjust to levy high rates on present consumers that provide funds for improvements they do not enjoy when paying those rates.

In cities where a proper depreciation and obsolescence fund has not been provided, it would seem necessary to set aside at once all surplus funds in a special sinking fund to make up for failures in the past to provide for this cost.

How then should the surplus be used? In every power plant there are at times emergencies that call for expenditures in excess of the current costs of other periods, such for instance as damages to the system from sleet storms, lightning, floods and fires. It would seem reasonable therefore that a special reserve fund of moderate amount should be set aside for this purpose out of the profits earned.

The use of surplus to provide for deficient depreciation funds has been pointed out. This procedure is so reasonable and rational that no argument need be presented to justify it, for sooner or later such funds must be forthcoming and rightly should be provided by the users of the utility.

When profits exceed reasonable allowances for the two preceding purposes, then the consumers are entitled either to a proportional rebate on their bills or to reduced rates for the following year. The former method has certain psychological advantages as it emphasizes the cooperative features of the enterprise and the mutual profit and loss characteristics of municipal undertakings, and also obviates the political pressure brought to bear on officials when rate changes are to be made.

If rates were reduced in proportion to surplus, the reductions would amount to from 7 to 15 per cent in the different cities, with the exception of Medicine Hat and Lethbridge.

Table VI contains some interesting deductions from Table V. Winnipeg figures are for the municipal plant only and do not include the large private corporation operating the street railway and also selling light and power in the city.

The plant equipment per 1000 inhabitants averages nearly twice that of the average of nineteen cities in Massachusetts. The electrical consumption per inhabitant is more than twice the eastern average.

The average of kw-hr. generated per kilowatt capacity of plant for the Canadian cities amounts to 1457 kw-hr. This indicates that practically the same station load per kilowatt installed exists in the West as in the Massachusetts cities. The equivalent coal per kw-hr. was figured from the cost of coal per ton of 2000 pounds and the fuel cost per kw-hr. as given in Table V. The Lethbridge plant consumes the whole output of its

TABLE VI.—GENERAL DATA ON PLANT OPERATION.

City	Plant capacity per 1000 inhabitants kw.	Debenture issue per inhabitant	Kw-hours generated per year per inhabitant	Kw-hours generated per year per kw. of plant capacity	Pounds of coal per kw-hour	Operating cost less fuel per kw-hour	Distribution cost per kw-hour	Overhead costs less taxes per kw-hour	Production cost less fuel and taxes per kw-hour	Fixed charges per kw-hour	Net Cost less fuel and taxes per kw-hour
Kamloops	491	$96.45	478	973	5.48	0.576	0.069	0.190	0.835	0.547	1.382
Medecine Hat	333	47.77	339	1016	....	0.417	0.109	0.117	0.647	0.912	1.559
Lethbridge	230	68.96	341	1484	6.25	0.753	0.254	0.275	1.282	1.351	2.633
Moose Jaw	150	35.39	187	1247	7.64	0.712	0.572	0.351	1.730	1.398	3.128
Saskatoon	238	41.91	388	1491	4.11	0.530	0.199	0.219	0.948	1.088	2.036
Regina	190	37.16	233	1226	5.23	0.582	0.272	0.181	0.982	0.874	1.856
Edmonton	205	56.60	438	2139	4.68	0.658	0.158	0.228	1.078	1.284	2.362
Calgary A	142	25.36	392	....	....	....	....	....	1.179	0.525	1.704
Calgary B	167	....	478	....	....	....	....	....	....	..	....
Winnipeg	150	35.92	312	2083	....	0.127	0.073	0.143	0.508	0.912	1.420
Average of 19 cities in Massachusetts	113	....	165	1462	3.12	0.338	0.423	0.344	1.252	....	....

" Calgary A " refers to the municipal plant only.

" Calgary B " includes the private corporation which has a franchise in the city. It has a plant of 2000 kw. capacity and delivers about 2,000,000 kw-hr. per year.

mine without much hand picking of the coal. The coal is rather low grade and high in ash. Hence the fuel consumption is apparently excessive.

The high coal consumption of Moose Jaw together with other high production costs is due in a large measure to the fact that half the boiler room was under construction during the financial year 1914.

Considerable high grade Pennsylvania coal was burned during the year at Saskatoon which partially accounts for the low coal consumption. A survey of these figures on coal indicates that power costs can be considerably reduced by improved plant

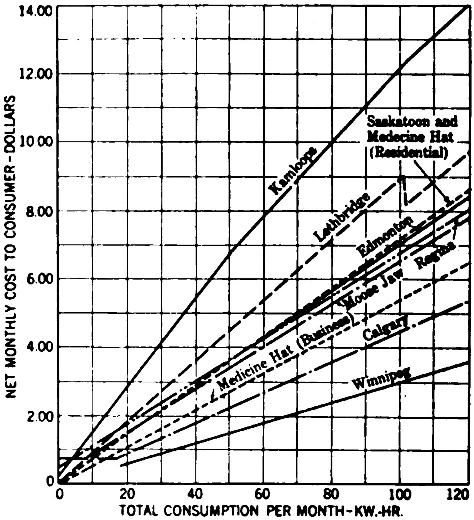

FIG. 2—MONTHLY LIGHTING CHARGES TO SMALL CONSUMERS

operation. The cost of fuel per kilowatt varies widely as shown in Table V. This item in the total cost was therefore eliminated from the figures given in Table VI in order that a more equitable basis of comparison might be obtained.

The column of "operating costs less fuel charges" indicates very clearly the influence of the high labor costs due to higher wages in the west as compared with those of the Massachusetts cities. Cheaper service may be expected then by reducing labor costs per unit of output as well as cutting down fuel costs.

Western distribution costs with the exception of Moose Jaw are generally low, possibly because the systems are comparatively new and have not needed extensive repairs. The item of taxes

was also omitted from the costs presented in Table VI as there was no uniformity of practise in regard to this charge. The office and management costs of these western utilities are low compared to the Massachusetts costs.

The average production cost less fuel and taxes is 1.021 cents per kw-hr. for the western cities against 1.252 cents per kw-hr. in the Massachusetts cities. The average fixed charges of the Canadian cities are 0.988 cent per kw-hr. or nearly the same as the production cost without fuel or taxes. The average net cost without fuel or taxes amounts to 2.009 cents per kw-hr. From Table V the average net cost including fuel and taxes is 2.793 cents per kw-hr.

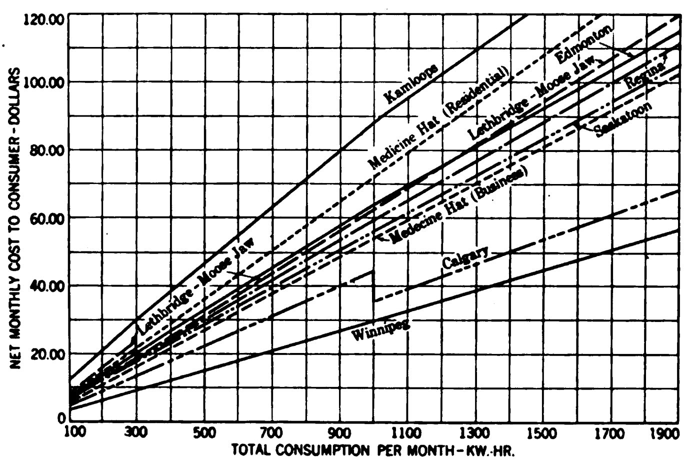

FIG. 3—MONTHLY LIGHTING COSTS TO LARGE CONSUMERS

RATES FOR LIGHT AND POWER SERVICE

The rates for lighting and power with the prompt payment discounts in the various cities are given in Tables VII and VIII, and are shown graphically in Figs. 2, 3, 4 and 5. These curves are plotted with total kilowatt-hours consumption per month per consumer as one ordinate while the other indicates the net monthly cost to the consumer when he avails himself of the prompt payment discounts. Comparison can be made between the different cities by selecting any given consumption and noting from the curves the net cost in each city. Rates of other cities can be compared by figuring the net cost of a given electrical consumption and comparing it with the charges in the Western plants as shown by the curves.

The curves showing the lighting rates for Regina for large consumers are not absolutely correct for they do not include the service charge of 50 cents per kilowatt of connected load. As no data are at hand in this case regarding the relation of connected load to consumption, it was impossible to plot curves representing true conditions. The actual cost can be found by adding the service charge to the figures given by the curves. The curve for charges to small consumers has been plotted on the assumption of one kw. connected load per customer, and may thus be slightly in error for any particular case. No attempt was made to show the two meter rates of Moose Jaw and other places.

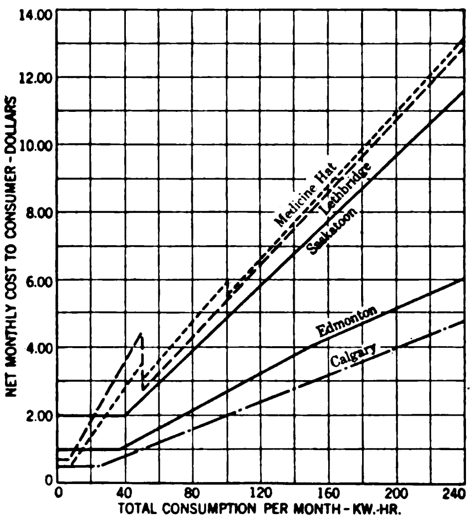

FIG. 4—MONTHLY POWER COSTS TO SMALL CONSUMERS

The effect of the general use of natural gas for domestic lighting and of the effort to build up a large power load is shown in the high domestic lighting rates at Medicine Hat.

A service charge of 50 cents per month per kilowatt of demand is charged at Regina against the customer. It is maintained that this covers the so-called "customer charge" consisting of the costs of reading meters, billing, etc., and also a portion of the demand charge on the plant which consists of the charges on capital to maintain capacity in the station ready to serve customers. Flat rates are also still in existence in some cities.

Medicine Hat, Lethbridge and Calgary charge for light and

power on a "sliding scale" basis, as shown in Figs. 3 and 5. In order to show the unfairness of rates charged on this basis take for example the Medicine Hat rates to two consumers using respectively 645 and 655 kw-hr. per month. The charges, are as follows:

1st consumer	645 kw-hr.	..	4½	=	$29.02
2nd	" 655	"	4	=	26.20

The second consumer uses 10 kw-hr. more than the first consumer yet actually pays $2.82 less for his total power. No analysis of costs could possibly justify such a practise, for the smaller consumer is manifestly discriminated against.

It has been pointed out that the large consumer is entitled

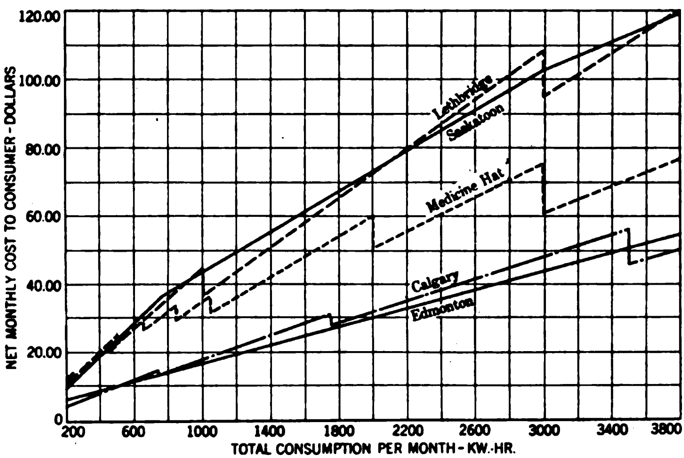

FIG. 5—MONTHLY POWER COSTS TO LARGE CONSUMERS

to some consideration in rates but these should be adjusted to the cost of service. Hence if an analysis of costs justifies the Medicine Hat rate of say 4½ cents per kw-hr. for the first 650 kw-hr. per month, then the consumer should pay that amount regardless of his total consumption. If, however, additional power over 650 kw-hr. can be provided to one customer at a lower cost than 4½ cents per kw-hr. then the consumer is entitled to a correspondingly lower rate for his consumption over and above the first 650 kw-hr. only.

General cost curves could not be plotted from the power rates given in Table VIII for the cities of Kamloops, Regina, Moose Jaw and Winnipeg.

TABLE VII.—RATES FOR LIGHTING.

KAMLOOPS.

Population 5500. kw-hr. generated 2,628,100

Flat Rate	10 c. p.	16 c. p.
Each light per month (not to exceed two lights)	1.25	2.00

Discount if paid within 10 days—20%.

Meter Rate.

First 50 kw-hr.	14 cents per kw-hr.
Next 50 "	12 " " "
Next 200 "	10 " " "
Next 700 "	9 " " "
Over 1000 "	8 " " "

1 cent per kw-hr. discount will be allowed if paid within 10 days from date due.

Meter rent 25 cents per month.

MEDICINE HAT

Population 9000. kw-hr. generated 3,050,070.

Private residential lighting	8 cents per kw-hr.
Business lighting	6 " " "

10% discount on bills paid in 10 days.

LETHBRIDGE

Population 10,000. kw-hr. generated, 3,415,000.

Up to 100 kw-hr. per month	10 cents per kw-hr.
101 to 300 " " "	9 " " "
301 to 600 " " "	8 " " "
Above 601 " " "	7 " " "

10 per cent discount on bills paid in 10 days.

MOOSE JAW

Population 20,000. kw-hr. generated 3,739,990.

Lighting Rate	7 cents per kw-hr.
Meter Rental	25 " " month
Minimum charge	75 " " "

10 per cent discount on bills paid in 10 days.

Customers may also use two-rate meters on which a charge of only 3 cents per kw-hr. is made for light, heating, cooking and small motors during off-peak hours.

Meter Rental	25 cents per month
Minimum charge	3.00 per month.

10 per cent discount on bills up to $40, paid in 10 days.

15 per cent discount on bills over $40, paid in 10 days.

SASKATOON.

Population 25,000. kw-hr. generated 8,873,642.

First 100 kw-hr. per month	8 cents per kw-hr.
Next 50 " " " "	7 " " "
All over 150 " " "	6 " " "

Minimum monthly charge $1.00.

10 per cent discount on bills paid in 10 days.

REGINA.

Population 40,000. kw-hr. generated 9,315,355.

First 300 kw-hr. per month	7 cents per kw-hr.
All over 300 " " "	6 " " "

Service charge 50 cents per kw. of demand.

Burned out lamps renewed by city free of charge.

10 per cent discount on bills paid in 10 days.

Special discounts for large lighting consumption.

EDMONTON

Population 50,000. kw-hr. generated 21,927,089.

1 to 100 kw-hr. per month	7½	cents per kw-hr
101 to 400 " " "	7	" " "
401 to 1000 " " "	6½	" " "
1001 to 2200 " " "	6	" " "
All over 2201 " " "	5½	" " "

Minimum monthly charge 75 cents.

No discounts allowed on account less than $1.00.

5 per cent discount on bills paid in 10 days.

The following schedule cover the charges for sign lighting

1 to 375 kw-hr. per month	5	cents per kw-hr.
376 to 5000 " " "	3	" " "
All over 5001 " " "	2	" " "

A schedule of minimum charges per kw. of connected load for each month of the year has also been prepared but is not quoted in this paper.

10 per cent discount allowed on bills paid in 10 days.

CALGARY.

Population 80,000. kw-hr. generated 31,391,596.

First 1000 kw-hr. per month	5	cents per kw-hr.
All above 1000 " " "	4	" " "

Minimum charge 75 cents for the first kw. of connected load and 50 cents for each additional kw. of connected load.

10 per cent discount on bills paid in 10 days.

WINNIPEG.

Population 200,000. kw-hr. delivered at city terminal 62,493,162.

Domestic lighting.......3¼ cents per kw-hr.

Minimum monthly charge of 50 cents per meter.

10 per cent discount on bills paid in 10 days.

Commercial lighting sells at the same rate but with a net minimum monthly payment of $1.00 per kw. of connected load and subject to certain wholesale discounts for large consumption not quoted.

TABLE VIII.—POWER RATES.

KAMLOOPS.

Population 5,500. kw-hr. generated 2,628,100.

Five classes of power rates are in effect, A for small motors; B for medium sized motors; C for large motors; D for irrigation pumping and E for heating and cooking off-peak.

Class A Power.

$6 per h. p. per year plus

First 50 kw-hr.	6	cents per kw-hr.
Next 100 "	4	" " "
All over 150 and under 500 kw-hr.	3	" " "

Class B Power.

$6 per h. p. per year plus

First 500 kw-hr.	3½	cents per kw-hr.
Next 1000 "	2	" " "
Over 1500 and under 2500 kw-hr.	2½	" " "

Class C Power.

$6 per h. p. per year plus

First 2,500 kw-hr.	3	cents per kw-hr
Next 4,000 "	2½	" " "
Next 5,000 "	2	" " "
Next 10,000 "	1½	" " "
All over 21,500 "	1¼	" " "

Class D. Irrigating only.

First 2500 kw-hr.	2½	cents per kw-hr.
Next 2500 "	2	" " "
All over 5000 "	1½	" " "

Class E. Heating and Cooking.

Off-peak load ... 3 cents per kw-hr.

Meter rent for all classes, 25 cents per month.

10 per cent discount on bills paid in 10 days.

MEDICINE HAT.

Population 9000. kw-hr. generated 3,050,070.

50 to 100 kw-hr. per month	6	cents per kw-hr.
101 to 250 " " "	5½	" " "
251 to 450 " " "	5	" " "
451 to 650 " " "	4½	" " "
651 to 850 " " "	4	" " "
851 to 1,050 " " "	3½	" " "
1051 to 2,000 " " "	3	" " "
2001 to 3,000 " " "	2½	" " "
3001 to 5,000 " " "	2	" " "
5001 to 25,000 " " "	1½	" " "
Over 25,000 " " "	1	" " "

Minimum charges, $1.00 per month per h. p., single phase motors.

$.50 per month per h. p. three-phase motors.

The following discounts are allowed on bills for prompt payment.

For the first $100 per month consumption		no discount:
For the second $100 " " "	excess over $100	10 per cent.
For the third $100 " " "	" " $200	20 "
For the fourth $100 " " "	" " $300	30 "
For the fifth $100 " " "	" " $400	40 "
From $500 to $1000 " " "	" " $500	50 "
Excess over $1000 " " "	" "	60 "

LETHBRIDGE.

Population 10,000. kw-hr. generated 3,415,000

There are three schedules in force, the Peak, the Off-Peak and the Flat Rates.

Peak Schedule.

Up to 50 kw-hr. per month	10	cents per kw-hr.
50 to 250 " " "	6	" " "
251 to 500 " " "	5½	" " "
501 to 1000 " " "	5	" " "
1001 to 3000 " " "	4	" " "
Over 3000 " " "	3½	" " "

Off-Peak Schedule.

Up to 100 kw-hr. per month	10	cents per kw-hr.
100 to 500 " " "	5	" " "
501 to 1000 " " "	4	" " "
1001 to 3000 " " "	3	" " "
Over 3000 " " "	2	" " "

10 per cent discount on bills paid in 10 days.

To obtain these off-peak rates the consumer must install a time switch which will be under the control of the city and be adjusted by the city to conform to the following hours
Between the hours of 1 a.m. and 6 p.m. from February 1st to December 1st.
" " " " 1 a.m. and 4. 30 p.m. from December 1st to February 1st.

Flat Rates.

These are quoted only for large sizes of motors and for use during off-peak hours and are not given here.

MOOSE JAW

Population 20,000. kw-hr. generated 3,739,990.

Horser power of motors or peak load	Fixed charges per h. p. per month or per h.p. of maximum demand	Meter rate per kw-hr. of consumption
1 to 3	$1.00	3.5
4 to 10	1.00	3.0
11 to 25	1.00	2.5
26 to 50	1.00	2.0
50 to 100	1.00	1.5
Over 100	1.00	1.25

Total charge equals fixed charge plus meter charge.

All charges are classified as follows:

Class " A "—24 hours unrestricted use 100 per cent of base rate.
" " B "—24 " restricted " 90 " " " "
" " C "—10 " unrestricted " 90 " " " "
" " D " 10 " restricted " 66.6 " " " "

The restricted hours are as follows:

October 15th to October 31st	5.30 to 6.30 p. m.
November 1st to November 30th	5.00 to 6.30 p. .m
December 1st to January 15th	4.30 to 6.30 p. m.
January 15th to February 16th	5.00 to 6.30 p. m.
February 16th to March 1st	5.30 to 6.30 p. m.

10 per cent discount on bills paid in 10 days.

SASKATOON.

Population 25,000. kw-hr. generated 8,873,642.

First 750 kw-hr. per month	5.4	cents per kw-hr.
Next 2250 " " "	3.25	" " "
Next 1000 " " "	2.34	" " "
Balance over 4000 " " "	2	" " "
Domestic power	4	" " "
Minimum charge	$2.00 per month.	

10 per cent discount on bills paid in 10 days.

REGINA.

Population 40,000. kw-hr. generated 9,315,355.

First 300 kw-hr. per month	5	cents per kw-hr.
Second 300 " " "	4	" " "
Third 300 " " "	3½	" " "
All in excess of 900 per month	3	" " "

Service charge of 50 cents per month per kw. of demand.

The city uses two-rate meters on which the off-peak rates are as follows:

First 1000 kw-hr. per month	3	cents per kw-hr.
Second 1000 " " "	2½	" " "
All in excess of 2000 " " "	2	" " "

The restricted hours are 6 p. m. to midnight from April 1st to September 30th, from 5 p.m. to midnight during March and October and from 4 p. m. to midnight from November 1st to February 28th.

10 per cent discount on bills paid in 10 days.

EDMONTON.

Population 50,000. kw-hr. generated 21,927,089.

Domestic Power not used for commercial purposes costs 4 cents per kw-hr.

Minimum charge 50 cents per kw. of connected load.

General Power Rates.

First 150 kw-hr. per month	3	cents per kw-hr.
151 to 300 " " "	2½	" " "
301 to 5000 " " "	1½	" " "
All over 5000 " " "	1	" " "

10 per cent discount on bills paid in 10 days.

The minimum monthly charges are as follows:

(a) Heating or apparatus other than motors, 50 cents per kw. of connected load.
(b) Single-phase notors up to 3 h. p., 50 cents per h. p. of connected load.
(c) Single-phase motors above 3 h. p., 25 cents per month per h. p. of connected load.
(d) Three-phase motors, 25 cents per h. p. of connected load.

In (a) and (b) the minimum monthly charge is $1.00.
In (c) and (d) the minimum monthly charge is $2.25.

Stand-by Service.

A minimum charge of $1.00 per kw. of connected load per month is made for this service No service is supplied for less than 25 kw. of demand.

CALGARY.

Population 80,000. kw-hr. generated 31,391,596.

1 to 750 kw-hr. per month	2	cents per kw-hr.
751 to 1,750 " " "	1.8	" " "
1751 to 3,500 " " "	1.6	" " "
3501 to 12,500 " " "	1.3	" " "
All above 12,500 " " "	1.1	" " "

A minimum charge of 50 cents per month per h. p. of connected load is made.

When the current is used during off-peak hours only and the amount of current exceeds 130 kw-hr. per connected h. p. per month, the following discounts are allowed:
5 per cent discount for consumptions of 130 to 250 kw-hr. per connected h. p. per month.
10 per cent discount for consumptions of 251 to 300 kw-hr. per connected h.p. per month.
15 per cent discount for consumptions over 300 kw-hr. per connected h. p. per month.

WINNIPEG.

Population 200,000. kw-hr. delivered at city terminals, 62,493,162.

Electric service heating, 1 per cent per kw-hr.

Alternating Current Power Rates.

The first	50	hours use per month of total connected load	3½c. per kw-hr.
"	50	" " " " " " " "	2.5c. " "
" "	50	" " " " " " " "	1.9 " "
" "	50	" " " " " " " "	1.4c. " "
" "	50	" " " " " " " "	1.1c. " "
Excess over	250	" " " " " " " "	0.8c. " "

Minimum monthly payment, 75 cents per h. p. of total connected load.
Prompt payment discounts 1 year contracts 10 per cent.

1 year contracts	10 per cent.	
3 " "	15 "	
5 " "	20 "	

All the above rates are subject to the following wholesale discounts:

For the first $100 per month consumption	no discount.	
" " second $100 " " "	excess over $100	10 per cent.
" " third $100 " " "	" " $200	20 "
" " fourth $100 " " "	" " $300	30 "
" " fifth $100 " " "	" " $400	40 "
From $500 to $1000 per month consumption	" " $500	50 "
Excess over $1000 per month consumption	" "	60 "

The first three charge a fixed sum per h. p. or per kw. connected per month, plus a power consumption charge. Winnipeg has a system of charges based on hours of demand. However, if plotted, the power rates of Regina would be nearly the same as those of Saskatoon, while Moose Jaw rates would likely fall

between Saskatoon and Edmonton as shown in Figs. 4 and 5. The off-peak schedules of the different cities were not plotted.

The Kamloops power rates could not be easily plotted.

These rates were plotted in curve form, not particularly to show absolute values, but to show how size of plant, cheap hydro-electric power and cheap fuel affect the cost of power to the consumer. Low first costs of plant and low fixed charges have an appreciable effect as can be seen by comparing these curves with the figures given in Tables V and VI.

The rates for Calgary are the lowest in the West with the exception of Winnipeg, due largely to the low cost of hydro-electric power.

The Medicine Hat plant serves power consumers almost entirely and its lighting rates are therefore high.

Edmonton rates should be reduced when the obsolescence charges are fully met.

Reductions may be expected in the rates of the other cities in proportion to the growth of the plant load, (for all of the power plants are now operating under normal loads) and with improvement of their load factors.

A comparison of Tables V and VIII shows that in many cities rates for power are quoted at less than net cost and often at less than production cost. It is held that power loads are necessary to build up the load factor and to increase the total output of the plant. In this way the cost per unit will be reduced. On the other hand, it is evident that if such consumers do not pay their proportion per unit, of the fixed charges and other costs, then other consumers—generally those using lighting only—are forced to pay an unduly large proportion of the costs if the utility is to meet its expenses. In such cases there is discrimination in favor of the large power users, who enjoy special privileges at the expense of the smaller consumers. This is unjust and the public can demand that this practise be stopped.

Another argument is that a low rate is quoted by the city as an inducement to industries to locate in its limits. It is maintained that any loss resulting from this low rate is more than offset by the benefits the city receives from having such an industry in its boundaries. This in the abstract amounts to a bonus to such an industry. The injustice of this plan lies in the fact that only the consumers of electricity pay this bonus, which logically should be paid in taxes by all the property owners if the municipality desires to give such aid to an industry.

But on the other hand, the costs of service, of meter readings and of office work are much less in the case of the large consumer than where the demand is small, and it is perfectly reasonable that he should be quoted a lower rate on these grounds. Nevertheless it is difficult to justify rates that do not cover the total operating costs plus fixed charges plus a portion at least of the distribution and office expenses. If the rates are based on service charges, it is proper for the large consumer to pay an equitable share of capital charges for his maximum demand on the station just the same as in the case of the smaller user.

The Winnipeg power rates deserve notice. The base rate does not vary with the size of the electrical demand, but varies with the duration of this demand per month. The logic of this rate is sound for its is evident that no consumer using power for over 50 hours per month could have this all on during the peak load hours. Thus a consumer using all his power for 200 hours per month provides a load two-thirds of which under any circumstances, must occur during off-peak hours. The large consumer only benefits by the liberal discounts given along with the rates.

The primary lighting rates in these Canadian cities have apparently been adjusted to favor the small consumer. The distance from oil-producing territory makes kerosene an expensive commodity. Hence in many cities, even the smallest householders find it not only more convenient but more economical to use municipal electric light than to burn kerosene lamps and these consumers, especially in those cities with minimum charges, provide a very considerable portion of the total revenue. In general the primary rates of cities in the United States exceed those of cities of similar size in Western Canada. Only a complete investigation by a public utility commission would show whether or not the small consumers are unduly favored in the latter cities.

A survey of the rates of privately owned plants in cities of similar size in Wisconsin as reported by the Railroad Commission of that state and in Massachusetts as reported by the Board of Gas and Electric Light Commissioners, indicates that in general their rates are considerably higher both for light and power than in the municipality owned utilities of these Canadian cities.

While it is possible, as already pointed out, that in some of these municipal undertakings adequate provision is not made for depreciation and obselescence, in most cases this could be provided out of surplus without appreciably affecting rates. Why

then should the Canadian cities be able to provide such rates? In the first place these utilities have no promotion or franchise expenses to capitalize and on which to earn a return. Nor have they capitalized "going value" or " good-will." In these particulars they have a decided advantage over the cities with privately owned plants.

Another feature is that in adjusting rates in privately owned plants, present value must necessarily be considered. In a growing city property increases rapidly in value and a private company is rightly entitled to earn money on the present value of its holdings or otherwise it would not pay the company to retain the property. In municipal enterprises any increment in value belongs to the city and does not need to be capitalized for rate making, although increasing the available assets of the utility and thus proving of value in issuing securities.

A third factor is the matter of returns on the investment. The Wisconsin Commission has ruled that companies are entitled to rates of from 7 to 8 per cent on their investment in order that capital may be induced to invest in them.

The Board of Gas and Electric Light Commissioners of Massachusetts report for 1914, dividends in privately operated electrical utilities ranging from 5 to 22 per cent. It is probable that those earning the biggest dividends are undercapitalized or that the plant has been largely built out of earnings.

The Canadian municipally-operated utilities are financed by debentures bearing from 4½ to 6 per cent interest. It is at once evident that there is an appreciable saving in this method of financing over that of private companies. This saving results in correspondingly lower rates to the customers of these utilities.

Finally the municipally owned utilities do not require a set of directors and higher officials who often draw extravagant salaries taken from earnings. The executive administration of these utilities is generally quite simple and efficient, the only high-salaried officials being the commissioner, the superintendent and the electrical engineer. Furthermore, it is not possible to milk the municipal utility for exorbitant fees for promotion and legal purposes and for receiverships and reorganizations. There is also no chance to manipulate earnings by means of subsidiary companies who supply power, own roadbeds or have other favorable concessions that enable them to take the cream from the profits of the utility itself.

Central Heating Systems

In the prairie provinces heat and pure water for cities are absolute necessities, the first to permit existence in cold weather, the second on account of the pollution of much of the local water with alkali or river mud. Light is less necessary than the other two. The people of these cities have cooperated in the establishment of their municpal plants to supply light and water but aside from the natural gas supply at Medicine Hat, have taken no steps to cooperate in the economical generation and distribution of heat. They do not seem to appreciate at full value the ease with which such a central heating system can be installed and operated, and the satisfactory financial and economic results that would be obtained from it. However, it must be kept in mind that a large portion of the population emigrated from Europe where such cooperative methods of heating are unknown. Hence this system is not understood and its full value has not been appreciated.

Hence none of these municipal plants has made any attempt to develop exhaust steam central heating in connection with its power plant. This would appear to be a promising field to exploit in those cities where coal is expensive and the winters long and cold, as in Saskatchewan. Where the power plant is centrally located, it should not be a difficult proposition to build tunnels at least through the business section for steam pipes, electric wiring, etc. and to derive a very profitable return therefrom. It should be possible to provide heat to consumers at a lower cost than by present methods. The conditions at Saskatoon seem to be favorable for this purpose as the old reciprocating engine could supply much of the exhaust steam needed. The old station at Regina could also be utilized for similar purposes and need operate only during the heating season.

General Remarks

The municipal electric light and power utilities of these Western cities have on the whole been run efficiently. Their rates are in general fair and reasonable and compare very favorably with those existing in cities of the same size in the United States where private corporations have control.

The public in these Western cities takes a great interest in all utilities and this in a large measure has made them keep up-to-date in equipment and organization. The economic effects of the low rates have not become apparent largely because the real

estate booms and inflated land values have offset the benefits of these rates.

Mistakes have been made in the past in the location and construction of electrical plants and in the selection of machinery. Most cities now have comprehensive plans prepared for plant extensions and only radical changes in prime mover designs would seriously interfere with carrying these out. The introduction and development of the steam turbine was such a change. At present, however, it does not seem likely that another new form of prime mover will be produced for a while at least.

It was a difficult matter to form any definite conclusions as to the character of service rendered by these municipally owned utilities. Since the war broke out, their electrical loads have been light and therefore they have been able to give excellent service as regards voltage control, lack of interruption, etc. It was therefore necessary to make inquiries over a period of years and these developed some interesting facts.

During the period of rapid growth in these cities the councils of the time were so engrossed in street extension, pavements, water projects, etc., that they could spare but little attention or funds for electrical plant needs. In consequence the plant was allowed to become overloaded from lack of sufficient equipment to properly handle natural increase of load. A series of interruptions in service would forcibly call the attention of the public to the critical conditions existing in the plant. Then a demand would be made for instant action and machinery would be purchased in many cases solely on the speed of delivery without particular attention being given to the ultimate station plans. This phase of municipal operation could be corrected by a utilities commission, which would have authority to regulate service before extreme conditions existed.

The administration of these utilities as has already been pointed out, is in the hands of either a commissioner, a superintendent or an electrical engineer and when these are free from interference on the part of the council, the utility is administered well and economically.

In a recent discussion of municipal plant operation in Oklahoma, Prof. Bozell makes the following statement:

> In practically every case where a cash surplus of any size was revealed, as well as in every case in which efficient operation and an intelligible accounting system were found, there proved to be someone in the munici-

pality who was devoting a large part of his time to the handling of the plant without any charge to the municipality.

A review of the utilities of Western Canada does not reveal any such condition to exist in these cities, for with the exception of Kamloops, the municipalities are large enough to employ competent superintendents.

In Manitoba, a public service commission has authority over public utilities. A similar commission has been appointed in Alberta since this investigation was made. But, at present there is no executive board in either British Columbia or Saskatchewan with such authority. Hence the municipal enterprises of these provinces are at the tender mercies of the common councils of the cities and towns. Such bodies have frequently in the past committed their municipalities to ill-advised extensions. It would seem advisable to have an executive board in each province organized along the line of the railroad commission of Wisconsin, who would have the necessary executive authority and with duties about as follows:

(a) To pass on all new extensions and expenditures of public utilities and to see that funds are spent on the improvements for which they are set aside.

(b) To receive and approve financial reports of the utilities and to adjust sinking funds and depreciation charges.

(c) To adjust equitable rates without discrimination and to scrutinize the disposal of surplus.

(d) To establish standards of service that the utilities can meet and that customers can reasonably demand. Owing to changes in the state of the art, these standards require frequent revision. Such changes usually result in improvement of service frequently at a lower cost.

(e) To collect engineering data and to provide engineering assistance to municipalities undertaking new enterprises. The commission should also be empowered to pass on the plans of all new projects.

(f) To advise with municipal authorities regarding the floating of debentures and to assist in a material way in marketing these. In many cases those in charge of the financial affairs of small towns have never had experience in these matters and competent assistance and advice would be most welcome.

Such a board should consist of only highly trained men experienced in this work and should preferably have three members, an engineer, an accountant and an economist. On no account should a man with a political record be allowed a place on such a board. In fact, it might be even advisable to appoint men from outside the provinces who would thus be free from local

prejudices and political affiliations. The board could act in an advisory capacity for municipalities on all matters dealing with utilities. Such control would have prevented many of the mistakes made in the needless extension of utilities and would have insisted on sound financial conditions in all utilities.

The establishment of such a commission would not necessarily curtail the control of any municipality over its own utilities. The local councils would still have the power to regulate rates, etc., subject only to review by the utilities board on appeal by one of the local consumers.

A further function of such a board would be to exercise executive control over the surburban and interurban activities of the utilities. Difficulties frequently arise in regard to the control, the rates and the service outside the municipal boundaries and beyond the control of of the city's authorities. These could be equitably adjusted by the commission.

Another useful activity of such a commission would be the standardization of the accounting systems of the various utilities. The difficulties met with in preparing the summary given in Table IV and the difference of opinion as to its accuracy as regards distribution of expense, make evident the need of such standardization if comparisons are to be made between the costs of different cities. Several of the public utility commissions in the United States have standardized utility accounting in a satisfactory manner.

Such mistakes as have been made by the executives of these municipal undertakings have not been intentional nor due to carelessness. Generally these errors were in connection with matters with which the official had no previous experience and at the moment lacked competent counsel. The inauguration of a friendly spirit of cooperation between utility executives and the proposed commission would do much to materially improve matters in the future, for the commission could be called on for consultation whenever new difficulties were encountered.

Conclusions

In the preceding discussion, emphasis has been placed on certain principles that should be applied to the organization of municipally owned utilities. These may be briefly summarized as follows:

(1) The utility should be entirely self-supporting, and consumers should be charged such rates that the returns will meet all the usual expenses of

the business but will not provide balances to be used in extensions or improvements or to offset losses in other departments.

(2) The utility should be under the direction of a single commissioner or superintendent holding office on good behavior and who should be given a free hand to develop the utility without political or civic-council interference.

(3) The utility should bear its portion of the cost of general municipal government through assessment and taxation. The latter should be paid from revenue and the rates to consumers should be adjusted to provide these funds.

(4) The utility should be financed by means of serial bonds instead of long term debentures and all such issues should equal only the life of the improvement they are intended to cover.

(5) Obsolete machinery should be written off the books at once either by using surplus funds or by increasing rates. Depreciation or replacement funds should be set aside from revenue to provide for the renewal of the plant when worn out.

(6) An emergency reserve fund of moderate amount should be accumulated out of surplus to meet extraordinary contingencies.

(7) All improvements and extensions should be financed by additional bond issues and not from surplus funds.

(8) The net surplus of the utility should be distributed in the form of proportional rebates to consumers.

(9) A public utility commission should supervise the finance, accounting, rates and administration of the municipal as well as privately owned utilities of each province.

The preceding discussion of facts and conditions connected with the organization, financing, operation, rates and service of the electric light and power utilities of these cities of Western Canada, leads one to the following conclusions in regard to the general criticisms of municipally owned public utilities stated in the opening paragraphs of this paper.

(1) The rapid growth of these cities has forced the executives of their utilities to make frequent extensions to their plants which on the whole are therefore well equipped with modern and efficient machinery and provide satisfactory service.

(2) Rates for lighting and power are as low and in many cases lower than those in force in cities of similar size in the United States and are reasonable charges for the service rendered.

(3) Accounting as a rule is now carefully done and the utility's finances are isolated from other accounts. Some of the methods of financing as regards debentures, sinking fund, depreciation and surplus as open to some criticism as shown in the preceding discussion.

(4) Most of these utilities have been fortunate in having good organization with competent executives.

(5) There may be isolated cases where politics has influenced the management of the utility. But there was nowhere evidence of the

application of the "spoils system" to the municipal plants and in the majority of cases, the utility has been tolerably free from political interference.

It must not be assumed that this paper is an endorsement of public ownership. An effort has simply been made to present the facts that came to hand during visits to the various cities, without bias either for or against municipal ownership. If this article seems to favor municipal ownership or control, it is only because the facts as they were found pointed in that direction. Such criticism and suggestions as have been made in this discussion are offered in a friendly spirit and in the hope that they may prove of benefit to these Western cities. In conclusion, the writer wishes to acknowledge the great assistance rendered him by the officials of these cities in the collection of data and in the inspection of plants and systems.

To be presented at the meeting of the Schenectady Section of the American Institute of Electrical Engineers, Schenectady, N. Y., March 7, 1916.

IRON LOSSES IN DIRECT-CURRENT MACHINES

BY B. G. LAMME

ABSTRACT OF PAPER

The term *iron loss*, as used in connection with rotating machinery, is shown to cover a large number of losses, some of which actually do not lie in the iron itself. The term *core loss* should be used except when the losses are actually located in the iron itself. It is shown that no great accuracy is practicable in the calculation of the actual iron losses, except in special instances, due to the fact that the ordinary treatment of materials in manufacture is such that large discrepancies are almost sure to occur, in certain types of apparatus. A brief explanation of several causes of variation in losses is given.

In the treatment of core losses in direct-current machines, the four principal sources of losses are considered, namely—armature ring loss, armature tooth loss, eddy currents in buried conductors, and pole face losses. Under eddy current losses is given an explanation of certain losses not usually taken into account, and a crude method of calculation is given, with some tabulated results.

Under pole face losses an empirical formula is given, also some tabulated results.

The effect of load on losses is discussed, but no calculated results are given. Some of the effects of flux distortion on the losses are shown.

A principal object of the paper is to show the impracticability of calculating all the core losses with any great accuracy at no-load, and the still greater difficulty in predetermining them with load.

IRON LOSS is a general term to cover a number of losses, of various kinds, which, by the nature of the tests, are included in one set of measurements and which, in reality, should be known as core loss. The term has been used so promiscuously, without indicating what it really includes, that many have come to believe that it means the true iron loss and nothing else. In fact, however, the true iron loss, in many cases, may be only a moderate percentage of the core loss. Usually no distinction has been made between losses simply located in the iron, and those due to the magnetic conditions in the material itself. The readily practicable methods of measuring the core losses show only their sum and there is no true indication of the relative values of the various com-

Manuscript of this paper was received January 20, 1916.

ponents. To separate the total core loss into its various components, except by complicated and expensive laboratory methods, appears to be almost impossible. However, it is possible to indicate the various components and their probable causes, and in some cases they can be segregated very crudely by calculation.

In most rotating machinery the calculation of the individual elements, which make up the total core loss, is necessarily only approximate, in commercial apparatus. This is due partly to the fact that there are many possibilities of variation in loss on account of conditions of manufacture and materials, as will be described later. This is evidenced by the fact that two machines, built at different times from the same drawings and the same tested grade of materials, will ofttimes show materially different core losses. If two such machines vary twenty per cent from each other in core loss, it is obviously impracticable to expect any refinement in calculation closer than twenty per cent. Even if we always could come within twenty per cent by direct calculation and could place any great reliance upon the results, it would be a great step ahead, in certain types of apparatus. In the discussion of the various losses and their causes, given throughout the following paper, it will be shown why it is impracticable to calculate, with any exactness, certain of these losses.

In separating the total core loss into its components, two principal classifications of losses may be made. One of these is eddy current loss, either in the iron laminations themselves or in other conducting parts wherein e.m.fs. are generated during rotation. Such e.m.fs. will set up local currents where closed paths are possible, and if such paths are in the laminations themselves, instead of in neighboring solid parts, it is simply incidental. Eddy current loss in the laminations is, therefore, not a special kind of loss, and it should rightly be classed with other eddy losses in the machine.

The second class of losses includes those due to changes in the magnetic conditions in the iron itself; these are known as hysteresis losses. These latter are dependent upon the material itself and not its structure. Lamination is primarily for increasing the resistance in the eddy current paths and not for the purpose of affecting the hysteresis. In fact, lamination may increase the hysteretic losses, for a given volume of material.

The principal object of this paper is to show causes for some of the principal losses. These are usually related to two sets of frequencies, namely, the normal frequency (revolutions per second times number of pairs of poles), and some very high frequency, dependent upon the number of slots, commutator bars, etc. The hysteretic losses are undoubtedly affected by these higher frequencies but apparently not to the same extent as the eddy losses. These high-frequency losses are liable to be present in most classes of rotating machines, while in some instances they may overshadow all other losses. Certain of them are characteristic of certain types of machines only, while others are liable to be present in any type of rotating machine.

In most classes of rotating machines, only the no-load core losses can be measured with any accuracy by ordinarily convenient methods of measurement. However, if the various components of the no-load loss can be approximately determined, then it is possible to indicate in what way these same components will be affected by load. A quantitative determination of the component losses with load is, however, very difficult to determine except in a very few classes of machines.

In direct-current machines the principal no-load armature core losses are the hysteresis loss in the iron, eddy losses in the iron and copper, and eddy losses in other adjacent conducting parts, which may be seats of e.m.fs. The relative values of these losses are dependent upon many conditions. In a thoroughly well designed machine the eddy losses in the copper and any other parts than the iron should be relatively small compared with the iron loss proper. Again, the proportion of hysteresis to eddy loss in the iron itself depends upon many conditions, such as the various frequencies in the machine, the grade of material, the degree of lamination, the perfection of the insulation of the laminae from each other, the distortion of the material in handling and building, the conditions of punching, treatment during assembly, grinding, filing, etc. Here, at once, so many variables appear that one cannot reasonably expect any great accuracy in any predetermination of eddy loss in the iron itself. Hysteresis loss is also affected by some of these conditions.

It is a fact well known to designers that the iron loss tables used by transformer engineers do not directly apply to rotating machinery, but that an increase, in some cases, of one hundred per cent or more is necessary, depending upon the

type of machine. This increase is due largely to additional causes of loss which do not occur to any appreciable extent in transformers. Some of these additional losses are as follows:

(a) Handling of iron. Experience shows that well annealed armature iron will have its losses very materially increased by springing or bending. If a lamination is given a decided bend, beyond the elastic limit, and then is straightened out, the loss at the part which has been bent may be increased as much as 100 per cent. This fact must be taken into account in machinery where armatures with many light teeth are used. Here it is almost impossible to prevent some abuse of the iron, especially in the teeth, which are the parts usually worked the hardest. Furthermore, tests have shown that if iron is bent, even at a small angle, and not beyond the elastic limit, the loss is materially higher with the iron in this strained condition, although the loss may return to normal when the iron is allowed to spring back to normal position. And if the iron is annealed in a curved or warped position, then when straightened out in building the strain is present, with increased loss. In building up armature cores, undoubtedly part of the iron is put under stress, especially in the teeth. Any dent in the iron, produced by hammering or otherwise, also tends to increase the loss.

(b) A second source of increased loss in the iron is due to the operation of punching. In shearing the iron a small amount adjacent to the sheared part is affected much in the same way as when iron is bent beyond the elastic limit. In transformer plates this strip next to the sheared edge represents but a very small percentage of the total volume of each plate or lamination. However, in armatures with many comparatively long narrow teeth, this sheared part may represent a relatively large percentage of the whole plate and, moreover, this is a part which often has the largest losses. But this may not have as great effect on the losses as another result of the shearing, namely, the sharp burrs which are left on the iron. These may be very small or almost negligible in appearance and yet represent quite a large percentage of the thickness of the plate. For example, a burr of two mils height, or 1/500 in., seems to be very small indeed, and yet it is about 12 per cent of the thickness of a 17-mil lamination. Dies must be maintained in very good condition to keep the burr below two mils. The effect of this burr is to bring increased thickness and pressure

at the edge of the sheets, particularly at the teeth. If the laminations are all turned one direction in building and the edges match perfectly the sheets might fit together so accurately that the burr would cause no extra thickness. But it is impossible to obtain such accuracy in practise and, therefore, the burrs of one sheet "ride" upon the surface of the next sheet, thus increasing the total thickness of the built-up iron. In practise, however, the iron is pressed down to approximately uniform height throughout. This means that the burrs carry considerable of the pressure at the armature teeth and there is more or less of a tendency to cut through the insulating film on the plates, thus increasing the eddy current losses. This is obviously a variable condition depending upon the accuracy of building, upon the condition of the dies, etc., and no method of calculation can take this loss into account with any accuracy. In small machines with low voltage per unit length of core, this loss usually is not of great importance. However, in high-speed large-capacity machines, it becomes increasingly important and in some cases special means are used for removing the burr before insulating the individual armature plates.

(c) Another source of iron loss, and one which also is beyond the scope of calculation, is found in the filing of armature slots and cores. In ideal armatures with perfect punchings and assembly, there should be no occasion for filing. However, the practise, in many cases where the armature iron does not build up with perfectly smooth surfaces in the slots, is for a limited amount of filing to be done. Usually this takes off only isolated high spots, so that the adjacent laminations are not bridged over to any great extent by the burrs due to filing. The tendency of most workmen is to file down to a nicely polished surface, whereas a coarse filing gives better results as it tends to break the laminations away from each other. Filing is most harmful in machines having a relatively high voltage per unit length of core. A milling cutter for cleaning out slots is usually worse than a file, as it produces greater burring of the edges. However, if the milling is followed by filing with a very coarse file the results may be just as satisfactory as with filing alone. Obviously, no method of calculation can show accurately the losses due to such burring.

(d) The iron losses are affected to a certain extent by pressure, that is, by the tightness with which the core is clamped.

The loss due to this is probably closely related to some of the preceding losses, such as bending and springing of plates, effect of burrs, etc. In small machines the effect of pressure apparently is of little moment, but in large very long cores it may become very appreciable. It is particularly noticeable in large turbo-generator armatures where the cores are very wide. In such machines, in attempting to draw the core down to a sufficiently solid condition as a whole, the parts next to the end plates are liable to receive abnormal pressure, with consequent increase of loss in those parts. For this reason, it is the practise in some cases to add an extra separation of paper at frequent intervals near each end of the core. Experience shows that this equalizes the losses and temperatures very materially. That this is due to undue pressure and not to stray field or other conditions, is indicated by the fact that when high temperatures are found in the iron, at each end of the core, very often the condition can be relieved by simply lessening the pressure to a comparatively small extent. The writer has known cases where the temperature in the end sections of the iron has been reduced 30 to 50 per cent by "easing off" the end plates. The total loss in the core may not be reduced very much, for the reduction in pressure usually affects only the end sections to any great extent. Presumably this loss is due to increased contact between the adjacent plates, possibly from the burr, but not entirely so, for similar results have been found in some cases where the burr had been fairly well removed before enameling the plates. The character of the enamel coating used for insulating purposes also has something to do with this.

In connection with pressure, the effect of heating of the core may be considered. Cases have been noted where the effect of high temperature of the core has been to increase the pressure between the laminations, due to expansion. This in turn increased the loss and thus still further increased the temperature. This effect has not been uncommon, to a minor extent, but a few cases have occurred where the combined pressure and temperature cumulatively have resulted in excessive core temperatures. In one case which the writer has in mind, a certain large machine operated for about two years without any noticeably high temperature in the core. Then, in a comparatively brief time, it showed evidence of increasing temperature until finally an entirely prohibitive tempera-

ture showed at one place. Examination showed that the core was very tight and all evidence indicated that increased temperature was causing increased pressure and thus further increasing the loss. In this machine, fortunately, the construction of the armature core and winding was such that the end plates could be released very easily about $\frac{1}{4}$ in. on each end. This was tried as an experiment and the temperatures all returned to the former normal of about 30 deg. cent. rise. As an interesting side issue, it may be mentioned that on this machine the armature teeth at each end of the core had been breaking off, although stout brass supporting fingers had been used. Apparently under the increased pressure, due to heating, the fingers would be bent away from the core, thus releasing the tooth laminations. Repeated tightening of the brass fingers did not relieve this condition. However, when the end plates were released $\frac{1}{4}$ in. at each end of the core, the brass fingers were then sprung in against the teeth and afterwards remained in position so that no breakage of tooth laminations was ever reported afterwards.

Obviously, with losses dependent upon pressure, no extreme accuracy in calculation of such losses is possible. However, in moderately small size machines, and especially in those of very moderate frequency and of very low voltage per unit length of core, the effect of pressure is not serious, within a moderate range of practicable pressures.

(e) Another source of iron loss, but which is not in the armature core, is that of the pole face, due to the tufting or bunching of the flux between the field pole and the armature teeth, where slotted armatures are used. Obviously, with all other conditions the same, this pole face loss will depend upon a number of variables in the lamination of the material itself. The effect of burrs from punching, the burring over of the surface due to turning, the effect of pressure, etc., all appear in the pole face loss. Therefore, it is evident that great accuracy in the calculation of such loss is impossible, in commercial apparatus. There are other conditions that affect this pole face loss which will be considered later under this subject.

Armature Ring Loss. The true iron loss in the armature ring is dependent upon the total flux per pole, distribution of flux, rate of change of flux, etc. The problem is much complicated by the fact that the flux distribution in the ring usually

is not uniform, that is, certain parts of the core have higher maximum densities than other parts. However, in ordinary practise the core densities used are relatively low, so that the losses can be approximated by averaging the inductions in certain parts. However, the rate of change of flux in the ring is dependent, to a certain extent, upon the flux distribution in the air gap and armature teeth, and this introduces some error, always in the direction of increased loss.

The distribution of flux in the armature ring is also dependent upon the effective length of the various flux paths. These latter will naturally depend upon various conditions, such as the number of poles, diameter of armature, flux distribution in the air gap and teeth, etc. Therefore, any method which does not take this distribution into account is necessarily only approximate. However, in practise there are so many other variables, as already described, in connection with manufacturing conditions, such as burring, filing, etc., that empirical rules have been developed, based upon numerous tests, which approximate the armature core loss in a standard type of machine about as accurately as any attempt toward exact calculation.

Armature Tooth Losses at No-Load. Apparently the flux densities in the armature teeth can be calculated with more accuracy than in the various parts of the core, for in the teeth the fluxes are limited to fairly definite paths. Therefore, exclusive of the losses due to manufacturing conditions, as already described, the tooth losses can be fairly accurately calculated, probably with much greater accuracy than many other losses, as will be described. The tooth losses may be considered further as follows:

The flux density in each individual armature tooth passes through a cycle, indicated by the shape of the field form. With the field form of the shape illustrated in Fig. 1, the tooth density will be a maximum at A, and this density will remain practically constant as the tooth moves toward C until the point B is reached. It will then decrease as the ordinate of the field form curve decreases and will reach zero value at C. The cycle of flux change is not sinusoidal, and therefore, the actual tooth iron loss should not agree with that represented by the usual iron loss curves based upon sinusoidal changes in induction. The difference, however, may be relatively small in the ordinary types of machines. The error may be

taken care of by some suitable correcting factor, which, of course, will be only approximate for the average case.

The density in the armature teeth is involved in the iron loss. This density is not uniform over the entire depth of the tooth, with the usual parallel-side slots, for the section of the tooth tapers off. This difference of section, in small diameter machines, may be very considerable. However, a higher density at the base of the tooth, tending to give higher iron loss, is compensated for, to some extent, by the reduced volume of material. In consequence, the mean section at some point from one-half to two-thirds the way down the tooth may be taken and the mean density and volume of material, based upon this section, may be used for approximating the iron loss. The accuracy of this method will be dependent, to some extent, upon the actual density used. For instance, if both the minimum and maximum densities in the tooth are relatively low, then the loss calculated for the mid-point density, at the mid-point section, will be closer to the true loss than if the maximum density is excessively high.

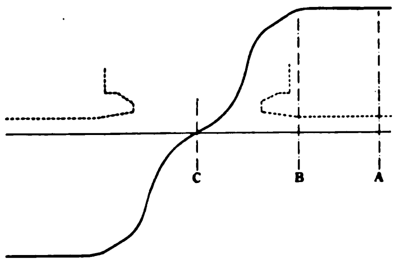

FIG. 1

Armature Copper Eddy Current Loss at No-Load. There may be a number of eddy current losses in the copper, some of which are of a minor nature. However, there may be two relatively large losses, depending upon the design of the machine. One of these is due to the flux from the field poles entering the armature slots and cutting the conductors. This is, to a certain extent, a function of the saturation of the tops of the armature teeth. It is also dependent upon the width of the slot opening compared with the iron-to-iron clearance. At first thought, one would say that the larger the air gap the more would the lines from the pole pass into the tooth top. However, the opposite is the case, for the larger the gap, the nearer do the lengths of paths into the slot approach to the iron-to-iron clearance, in percentage.

In moderate size machines with relatively small air gaps and moderate slot widths, the eddy current loss from fringing into the top of the slot is comparatively small, and, as a rule,

no special precautions need be taken to minimize it. This particular loss is usually greatest in high-voltage, large-capacity turbo-alternators, where relatively wide slots, up to 1.5 in. or more, may be used, and where the air gaps are very large. In such cases lamination of the top conductors to avoid eddies from this cause may be desirable.

The second source of eddy current loss in the copper, which is liable to be larger than all others combined, is due to the peculiarities of flux distribution in the armature teeth. Let Fig. 2 represent the magnetic conditions in a given machine. It is evident from this figure that under the central flat part of the field form, the armature teeth are worked at a uniform induction, assuming that there is no field distortion. However, at the edges of the pole the tooth density decreases slightly. If the saturation of the teeth under the flat part of the field form is very high (materially above 120,000 lines per sq. in.), the ampere-turns required to magnetize the teeth may be very considerable. However, at the edge of the pole a comparatively small decrease in the flux density in the teeth (15 to 20 per cent) will mean a relatively enormous decrease in the ampere-turns for the teeth. For instance, the tooth *c* in Fig. 2, under the central flat part of the field form, may require 2000 ampere-turns, while the next tooth *b*, under the pole edge, which is worked at possibly 20 per cent lower density, may require only 10 to 20 per cent as many ampere-turns. Assuming such conditions, then the magnetic potential at the top of tooth *c* will be higher than that at the top of *b* by 1600 to 1800 ampere-turns. Therefore, under this condition there will be a very considerable flux across the slot between *c* and *b*. A little earlier or a little later in the rotation this flux across this slot will not exist to any extent, for the ampere-turns for *b* and *c* will then both be comparatively low or very high, while the difference between them will be small. In consequence, near each pole edge, there is a very rapid rise and fall of flux across the armature slots. This is illustrated in Fig. 2.

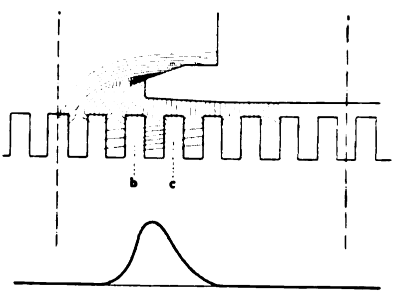

FIG. 2

Obviously, the armature conductors lying in the path of

this flux will be the seat of e.m.fs. which will tend to set up local currents, the value of which will be some function of the e.m.f. producing the current, of the dimensions of the conductor, etc. If the flux across the slot is large, this e.m.f. may also be considerable, for the rate of this flux change will be high compared with the normal frequency of the machine. As the e.m.f. generated is a function of the maximum difference between the ampere-turns required for two adjacent teeth and as the loss in any given case will vary as the square of the e.m.f., obviously the loss in one slot will vary as the square of the maximum difference between the ampere-turns of two

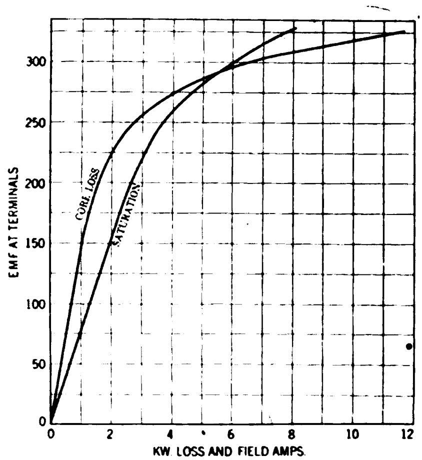

FIG. 3

adjacent teeth. At very high saturation, the maximum difference between the ampere-turns required for two adjacent teeth may be relatively high and the loss may be correspondingly great. Due to the shape of the permeability curve of steel at very high saturation, the difference between the ampere-turns of two adjacent teeth may increase faster than the square of the terminal e.m.f. Therefore, the eddy current loss due to this cause may increase faster than the *fourth power of the total induction per pole.* Evidently, therefore, it is desirable to keep these eddy current losses at a low value at no-load, for the high tooth ampere-turns under the distorted field conditions of full load will tend to increase the percentage of these losses very greatly. Fig. 3 shows a characteristic core loss

curve for a generator in which the copper loss, due to the above cause, is very large at the higher e.m.fs.

Several years ago, the writer spent considerable time in attempting to determine the value of this eddy current loss at no-load. Neither sufficient nor entirely satisfactory data were available. From the data at hand, the following empirical formula was derived, which appeared to accord fairly well with the facts in a number of cases which were worked out. This formula applies, however, only to windings with two conductors in depth per slot. This formula for the loss in conductors is

$$\text{Watts loss} = \frac{180\ V_c\ R_s\ p\ (1000 + a)^2}{10^8}$$

a = Maximum ampere-turns for one tooth.
V_c = Total volume of copper, in cubic inches, in one slot.
R_s = Revolutions per second.
p = Number of poles.

The values for the watts eddy current loss in the copper were approximated by taking the iron loss curves at the lower e.m.f. values (where the above eddy current loss would be very low), and then projecting them for the higher values according to the laws which the iron loss alone should follow. The difference between this corrected iron loss and the actual test curve was assumed to consist largely of eddy current loss. As this difference usually increased very rapidly at higher inductions, the above assumption was in line with the preceding statements that this eddy current loss may increase much more rapidly than the square of the flux. In this determination obviously the pole face loss would have to be taken into account. This was taken care of as far as possible, by tests with relatively large air gaps, the pole face loss thus being very small.

It may be noted that in the above empirical formula, the ampere-turns for one tooth under the maximum field has been used, instead of the maximum difference between the ampere-turns of two adjacent teeth. However, the tests indicated in general that the maximum difference was approximately proportional to the maximum ampere-turns in one tooth and, therefore, it was simpler to use the total turns for one tooth. Also, where the total tooth ampere-turns are tapered off over

several teeth, the difference between the ampere-turns for adjacent teeth is reduced, but more slots and more copper is involved, whereas the empirical formula includes only the copper for one slot. Various attempts were made to include all the different factors, such as ampere-turns across each slot, number of slots, number of conductors involved, counter magnetomotive force of the eddy currents, etc., but none of the resulting formulas gave as consistent results as the above. It must be admitted that this formula is an extremely crude one, but it happened to fit most of the cases that the writer was able to analyze. In deriving this equation, it was found that if the loss was assumed to vary directly as the square of the tooth ampere-turns, then it would be too great at very high tooth saturation. At high tooth densities, the flux across the slots, at the pole edge, is distributed over several successive slots, so that the maximum difference between the ampere-turns of two adjacent teeth bears a lower proportion to the ampere-turns for one tooth. Also, at very high tooth densities there is more or less fringing of flux down through the slot, in parallel with the tooth flux, and this makes the determination of the actual tooth flux difficult. In the formula, therefore, the term $(1000 + a)^2$ is used in place of a^2 to take care of these conditions. This term, however, is obviously wrong, in that it indicates a loss when the tooth saturation is negligible. However, this loss under low saturation usually works out from the formula to be of comparatively small value, so that the error is not of much importance.

A modified formula, which agrees with the above fairly closely at high saturations, but gives no loss at zero saturation, is the following:

$$\text{Watts loss} = \frac{135\ V_c\ R_s\ p\ (4000 + a)a}{10^8}$$

The following table shows the comparison of the copper eddy loss compared with the calculated loss by the first formula above, for a number of machines. It will be noted that the agreement is not particularly close, but possibly as good as could be expected, considering how the test losses were derived. It may be stated that these were all comparatively old types of machines, for in recent years great pains have been taken to eliminate large eddy losses of this character, so

that it was necessary to go to old machines in order to obtain exaggerated cases.

Kilowatt rating	Terminal e.m.f.	Rev. per min.	No. of poles	Calculated ampere turns in teeth	Eddy loss estimated from test curve; kw.	Eddy loss calculated from formula; kw.
340	600	685	6	1400	2.7	3.4
"	700	"		3000	10.0	9.7
500	600	225	10	2500	7.5	6.15
"	625	"		4000	17.5	12.5
750	250	514	10	1200	1.5	2.76
"	320	"		7200	32.0	39.3
750	550	514	8	1500	4.5	3.3
"	700	"		7000	33.0	36.5
1000	250	514	12	600	2.5	2.2
"	330	"		6000	50.0	41.3
1000	600	514	10	1225	4.5	4.6
"	700	"		2380	10.0	11.3
2000	575	300	14	3000	12.0	7.1
"	675	"		7000	36.0	28.2

Pole Face Losses at No-Load. It has long been known that, with open slot armatures, there are liable to be considerable losses in the field pole faces due to bunching of the magnetic flux from the armature teeth to the pole face, the armature teeth thus acting as small poles of an "inductor" type alternator, of which the pole face, to a small depth, serves the function of the armature core.

While the effect of this "inductor pole" action has long been known, the amount of loss due to it has frequently been underestimated, especially in machines with relatively small air gaps compared with the width of the armature slots.

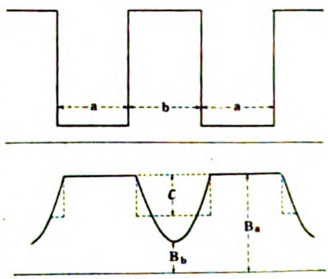

FIG. 4

The following crude description will illustrate the extent of the variations in flux in the air gap due to the open armature slots. In Fig. 4, a represents the width of one armature tooth and b represents the width of one armature slot. Let g represent the single air gap (iron to iron).

In the lower diagram, which represents the flux distribution in the air gap, let B_a represent the flux density in the air gap

under the armature teeth and B_b the minimum flux density corresponding to the center of the slot.

Then, $a \times B_a$ = the total flux under one tooth, for unit width of core, and $b\ (B_a - B_b)\ c$ = the total decrease in flux for the space covered by one slot. c represents the average height of the curve *def* in Fig. 4. If this curve be assumed to be sine shaped, then c would be 0.636. Any other shape which would be likely to be found in practise would not be far from this value. A V-shape, as one extreme, would give $c = 0.5$, while a circular shape, as the other extreme, would give $c = 0.784$. Apparently the value would lie somewhere between these two extremes.

In calculating the effective gap from the above diagram and assumptions, the following equation would be obtained:

$$\text{Increased gap } g' = g \times \frac{(a+b)\ B_a}{(a+b)\ B_a - b\ (B_a - B_b)c}$$

$$\text{Or, } g' = g \times \frac{1}{1 - \dfrac{b\ (B_a - B_b)\ c}{(a+b)\ B_a}} = g \times \frac{1}{1 - \dfrac{(b)\ (B_a - B_b)\ c}{(a+b)\ (B_a)}}$$

The resemblance of this equation to Carter's well-known equation for the increased air gap may be seen at once.

$$\text{In Carter's equation, } g' = g \times \frac{1}{1 - \dfrac{b\ k}{a+b}}$$

Comparing these two formulas, it is evident that k =

$$\frac{(B_a - B_b)\ c}{B_a}.$$

An extremely close approximation to k can be obtained from the empirical formula $k = \dfrac{\frac{b}{g}}{5 + \frac{b}{g}}$. This holds closely

to Carter's curve over almost the entire range. Equating the above two values of k, we obtain the equation

$$\frac{B_a - B_b}{B_a} = \frac{1}{c} \frac{(b)}{(5g + b)}$$

Or,

$$\frac{B_b}{B_a} = 1 - \frac{1}{c} \frac{(b)}{(5g + b)}$$

This gives the ratio of the flux density at the middle of the slot to the flux density under the tooth.

As an example of what these relative values may be, assume that $a = b$, or the slot width = the tooth width, and that $g = 0.25\ b$, which is extreme for large a-c. or d-c. generators, but not unusual for induction motors. Assuming $c = 0.635$, then $\frac{B_b}{B_a} = 0.3$, or the density under the middle of the slot is only 0.3 of that under the tooth. With these same values, the value of g' becomes 1.2859, or the gap increase is 28.5 per cent, which is not unusual for some machinery. Obviously, a variation in the flux density at the pole face of 70 per cent should tend to give high iron losses in the pole face itself. In fact, some of the inductor type alternators which were in common use a few years ago did not give variations in armature flux materially better than indicated by the above value. Such proportions as the above example would, therefore, be fairly good for an inductor alternator.

The above analysis is given simply to furnish a means for determining the possible variations in the flux density which may be obtained with open slots. This gives a much better conception of the problem than can usually be obtained directly from Carter's formula for the increased length of gap. It also gives a good idea of the possibilities of tooth losses in those cases where the teeth of one element or member of a machine alternately pass under the teeth and slots of the other member.

Considerable work has been done at various times to determine the pole face losses due to open armature slots. The difficulty in determining a workable formula is very considerable, as there are many conditions which may directly or indirectly affect this loss. For example, the thickness of the

laminations, or the material in the pole face, may have an influence. Any general formula for this loss would require different constants for different types of pole faces. One formula for this loss has been given by Professor C. A. Adams and his associates.* The formula is very complex and somewhat difficult to use.

A much simpler formula for laminated pole faces is as follows, for 0.031-in. laminations:

$$\text{Watts loss} = \frac{75\, b\, E^2}{C_f\, W_s^2\, g\, L} \sqrt{\frac{S_c}{R_s\, g}}$$

E = Generator voltage.
b = Width of slot.
g = Single air gap (iron to iron).
W_s = Armature wires in series.
L = Width of pole face.
C_f = Field form constant.
S_c = Total slot space = width of slot $\times$ No. of slots.

It is very difficult to obtain any reliable data on pole face losses alone, for other core losses are liable to be included in any tests. Variation of air gap, with everything else in the construction unchanged, gives a partial measure. However, this changes the field form somewhat and thus modifies the

Pole Face Losses, by Comfort A. Adams, A. C. Lanier, C. C. Pope and C. O. Schooley. PROC. A. I. E. E., July, 1909, page 1151.

$$W_p = S_p \times p \times 0.000462 \left(\frac{B_g}{10^4}\right)^{2.4} \times \left(\frac{v}{10}\right)^{1.55} \times q^{1.5} \times \frac{1}{t_p}$$

W_p = Pole face loss.
S_p = Section of one pole face (average section where the density is B_g).
p = Number of poles.
0.000462 = Constant for $\frac{1}{16}$-in. laminations.
B_g = Density in the gap over the section S_p.
v = Velocity of the armature surface in feet per second.
q = Ratio of width of slot to air gap.
t_p = Tooth pitch in inches.

tooth saturation and the tooth and eddy losses, to a certain extent, thus rendering doubtful the pole face component.

The above formula is necessarily approximate and applies only to laminated pole faces. The effect of cutting away part of the laminations in order to produce high saturation at the pole face is not included. However, it is possible that this may not influence the loss to any great extent. The greater part of the loss is represented by eddy currents, and cutting away part of the laminations will tend to break up the losses between plates and this may compensate to a considerable extent for the higher densities in the remaining plates. It is hoped that some time in the future more complete data may be obtained, over a sufficiently wide range of conditions, to cover the practical range of ordinary design.

The following table covers a number of machines with adjustable air gaps in which the pole face losses were worked out according to the above formula. Also, the total calculated and the total test losses are given, to indicate the agreement in a general way. The writer is perfectly willing to admit that he believes that the fairly close agreements between some of the calculated and test totals are largely accidental, and they should not be taken as proof of any great accuracy of the methods.

It is obvious from this table that the pole face losses may be comparatively high in some cases, provided the formula is reasonably correct. Evidently, if these losses could be calculated with any great accuracy, the design of the machine might be considerably modified, compared with more recent practise, with advantageous results. The pole face losses will evidently be greatly increased by field distortion when the machine is carrying load. Eddy currents in the copper are also affected by field distortion, and a correct method of calculating both the eddy current and the pole face losses with various loads should lead to considerable modification in the proportions of d-c. machines, in general.

Stray Losses. Under this heading may be included a number of no-load losses which are usually of a minor nature. Among these may be included secondary losses in the armature winding due to unsymmetrical cross-connections or unbalanced voltages in parts of the winding which are connected in parallel. There are various possibilities for losses from this source and, in consequence, it is always advisable to use armature wind-

Kw.	E.m.f.	Rev. per min.	No. of poles	Single air gap; inch	No. of slots	Width of slots; inch	Tooth ampere-turns	Pole face watts	Calculated core losses				Total test losses watts
									Copper watts	Core watts	Teeth watts	Total watts	
200	250	1150	6	0.156	64	0.406	1635	2060	3660	1200	2500	9420	8500
				0.125			1887	2870	4400	1200	3000	11470	11600
200	250	1200	6	0.25	72	0.391	275	975	895	670	1450	3990	3800
				0.125			395	2200	1075	670	1650	5595	7300
750	250	514	10	0.25	200	0.312	2520	2530	7010	2560	5100	17200	19800
				0.1875			2820	3860	7410	2560	5320	19150	22000
750	550	514	8	0.375	200	0.328	2650	1190	7375	1945	3780	14290	14000
				0.250			2840	2210	7770	1945	4000	15925	15550
1000	600	514	10	0.281	140	0.625	2050	6380	15060	5290	6200	32930	30800
	700			0.281			3750	8680	36500	8320	7800	61300	62500

ings which are as symmetrical as possible. Also, the arrangement of the winding should be such as always to generate balanced e.m.fs. in parallel circuits. This condition is not infrequently overlooked in the design of direct-current machines.

A second cause of undue loss in the armature winding may be occasioned by short-circuiting one or more of the armature coils under an active field. The brushes may be shifted from the magnetic neutral point so that some of the armature conductors are short-circuited under the main field flux; or the neutral point may be so narrow and the brush so wide that some of the armature turns are short-circuiting in an active field, even when the brush is set for the no-load neutral. An armature winding which is considerably "chorded" in a field with a narrow neutral point may have two sides of a coil short-circuited in fields of the same polarity. The e.m.fs. in the two sides of the coil should, therefore, balance each other if the brush is set at the true neutral. However, if the brush short-circuits several coils or turns, obviously only one of them can be at the true neutral and have balanced e.m.fs. set up in its two halves. The other turns may have more or less local current in them, which may be a source of considerable loss.

A third condition may occur when there are considerable pulsations in the reluctance in the air gap under the main poles as the armature teeth move under the poles. This varying reluctance usually gives varying main flux and at a relatively high frequency. The armature coils short-circuited by the brushes will act as secondaries to these pulsating fluxes and in consequence there may be some loss in the short-circuited coils due to this cause. Any solid parts of the yoke or poles may also have losses due to this cause. Usually, however, such losses are small.

A fourth source of loss may rise from stray fluxes from the main fields to the armature, which do not pass through well laminated parts of the armature core. For instance, the ventilating spacers may be so dimensioned and shaped that eddies can be set up in them. Also, the finger plates at each end of the core, the end plates, etc., may carry light fluxes which produce some loss. Bands on the armature core or at the ends may also be the seat of e.m.fs. and will have some loss in them. These losses are difficult to determine, and, in practise, should be eliminated as far as possible.

Full Load Losses

It is evident from the foregoing that the no-load core losses are dependent upon so many variable conditions that there can be no great accuracy in predetermining such losses unless all the details of construction, material, treatment, etc., are known for each individual machine. The impossibility of accurate calculation is shown by the fact that the individual machines built on the same stock order will vary considerably from each other, especially in certain types.

While the no-load losses are difficult to predetermine, the full load losses are still much more difficult to calculate, as will be shown in the following rough analysis. Here, the effects of flux distortion by the armature magnetomotive force tend to exaggerate the pole face losses and those in the armature copper, which are the two relatively large losses which are most difficult to calculate at no-load. Also commutation and brush losses, due to load, now enter into the problem. The individual core losses may be considered briefly as follows:

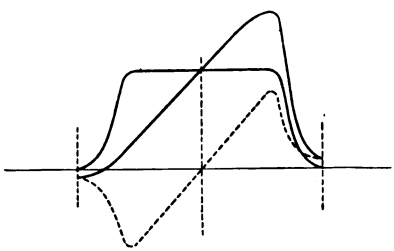

Fig. 5

Armature Ring Loss, with Load. This loss should not change greatly with load, provided the total flux at load is practically the same as at no-load. Under this condition a variation in the distribution of this flux is about the only factor which should produce any material change in loss. The full load field form may be illustrated by Fig. 5. It is evident from this figure that the flux is now crowded toward one pole edge and, therefore, the major part is concentrated in a narrower space. The average length of the flux path may, therefore, be somewhat greater than at no-load, but in some cases this may tend to distribute the flux more uniformly through the depth of the ring. However, where the flux enters the core at the base of the teeth there will be slightly more crowding and, therefore, somewhat increased loss. Taking everything into consideration it would appear that, in general, the armature ring loss can be considered as practically constant with constant total flux and speed, independent of the variation in load.

In variable-speed and adjustable-speed d-c. machines, the armature ring loss may vary over a wide range due to changes in total flux and speed. Such cases are difficult to calculate with any degree of accuracy, although no more so than other losses in the same machines.

Armature Tooth Loss, with Load. As shown by Fig. 5, the tooth flux density at one edge of the pole is decreased and at the other edge is increased when the field flux is distorted by the armature magnetomotive force. The increased density in the armature teeth means increased iron loss and, if the distortion is very great, the increase in tooth loss may be very large, being in some cases even doubled or trebled, compared with the no-load tooth loss. No direct rule can be given for the calculation of this loss, except that it may be determined approximately by calculating the flux distribution with load and thus determining the flux densities in the teeth.

In variable-speed and adjustable-speed machines, particularly in the latter, the tooth loss with load will be affected very considerably by changes in both speed and total flux. In variable-speed machines of the series type, reduction in speed usually accompanies increase in total flux, so that, as regards the losses, one effect partly neutralizes the other, so that the increase in tooth loss with load may be less than in a constant-speed machine. In adjustable-speed machines, however, especially in those of constant horse power and constant voltage, the tooth losses will vary over a very wide range with change in speed. Here, the armature magnetomotive force is constant (assuming a constant horse power) and the field flux is varied from a maximum value at lowest speed to one-quarter value at four times speed, assuming a four-to-one range. The total flux, therefore, varies inversely as the speed and the two effects should nearly compensate each other, as regards losses, if it were not for the variation in flux distortion. At lowest speed, with considerable saturation in the pole horns and armature teeth, the armature magnetomotive force, even if relatively large compared with the field magnetomotive force, may not produce very large distortion, so that the tooth loss is not increased excessively over the no-load tooth loss. However, as the field is weakened, the armature magnetomotive force remaining constant, the distortion is relatively increased, so that the peak value of the distorted field may remain almost constant in height. As the armature tooth losses are dependent

upon the peak value of this field, then obviously the combined effect of this field and the increase in speed will mean very greatly increased tooth losses. With very low field magnetomotive force, the distortion may be so great as to give a double peak, as indicated in Fig. 6. This double peak gives, to some extent, the effect of a double frequency and thus further increases the loss.

Eddy Currents in Copper. When the field form is distorted, with load, the ampere-turns in the teeth at one pole corner are greatly increased, while those at the other corner are decreased. Therefore, there will be an increased loss in the copper at one pole edge and a decreased loss at the other pole edge. However, as this loss at high inductions will vary almost as the square of the ampere-turns in the armature teeth, it is evident that the reduction in the loss at one pole corner may be small compared with the increase in loss in the copper at the other pole corner. The resultant loss can be calculated approximately by using the formula already given for no-load conditions, but with the ampere-turns in the teeth based on the load conditions. This would give a loss corresponding to no-load with the maximum induction in the teeth raised to peak value with load. This would include losses for the two pole corners; therefore, the result should be halved, as the peak density occurs at only one pole edge.

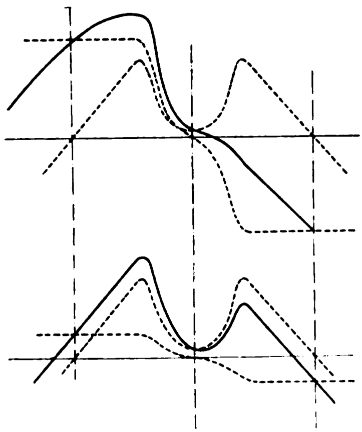

FIG. 6

If the empirical formula given for the copper loss represents the facts, even to a roughly approximate degree, the results are very startling when applied to some of the old-time machines. The calculations show that in some cases the eddy current copper loss at heavy load was several times greater than at no-load. This should be true, but to a much less extent, in more modern types of machines. The results indicate that in many cases there would be considerable gain by reducing the field distortion through high saturation in the pole face, pole horns, etc. This saturation, however, would have to be

so arranged as to give the most beneficial field distribution with load, and haphazard methods of cutting off pole corners, without regard to the field form with load, would have to be avoided. In fact, in the past, the cutting away of pole corner laminations, in many cases, has been largely for the purpose of improving commutation, and not to obtain the best field form with load.

Pole Face Losses, with Load. The pole face losses will obviously be affected locally by change in the flux density in the air gap or at the pole face. Field distortion will tend to increase the loss at one pole corner and decrease it at the other. The increase will usually considerably exceed the decrease, but the resultant will not be increased in anything like the same proportions as the copper eddy current losses under the pole corners are increased with load. A rough approximation for the increased iron loss could be obtained by comparing the squares of the densities, at several points along the distorted field form, with the squares of the densities of the no-load field form corresponding to the total induction.

As the increase in pole face losses with load will, in some instances, be considerably less than the increase in the eddy current losses, it might be advantageous in such cases to decrease the field distortion by pole face saturation, even at the expense of increasing the no-load pole face losses. For example, if, in an extreme case, the air gap were decreased 20 per cent and the air gap ampere-turns thus gained were expended in suitably saturating the pole face material, then the full load field distortion might be much less than with the larger gap, with the same total field magnetomotive force. The no-load eddy current copper losses would be practically unchanged, while the no-load pole face loss would be increased. However, the full load pole face loss, due to the reduced distortion, might be no greater than with the larger gap, while the eddy current losses in the copper might be very much less than with the larger gap. In consequence, while the total no-load losses would be increased somewhat, the full load loss would be smaller than before, and the carrying capacity of the machine would be actually increased. This would apply, however, only to those machines where the no-load eddy current and armature tooth losses are relatively high and where the distortion is rather large with load.

Stray Losses. When the machine is carrying load, the stray

losses given under the no-load conditions may also exist and at the same time some of these may be greatly exaggerated. Also, other losses may appear which are not found at no-load.

Copper loss due to short-circuiting the armature coils in an active field will sometimes be more pronounced than at no-load, particularly in non-commutating pole machines in which the brushes are shifted into an active field to produce commutation. This field, as a rule, will only be of proper value to produce proper commutation at some definite load, while at other loads there may be very considerable local currents in the short-circuited coils which may produce loss.

As the main field flux is crowded toward one pole corner and the field form becomes more pointed in shape, the effect of variable reluctance in the air gap may become more pronounced than at no-load, and, therefore, pulsations of the main field flux may cause more loss in the short-circuited armature coils.

Stray fluxes from the main poles will be distributed differently from the no-load condition and the densities of these stray fields may be considerably higher at certain points and thus give increased losses.

Additional losses at full load may be due to fluxes set up by the magnetomotive force of the armature winding itself when carrying load. For instance, the armature winding will set up magnetic fields, through the end windings, which fields are fixed in space, in a rotating armature machine. Bands or supporting parts, or other solid metal, rotating with the end winding, may cut these stationary fields or fluxes, and thus losses may be set up which are a function of the load.

Another source of loss at load may be found in the operation of commutation itself. A magnetic field or flux is set up by the armature winding across the slots from one commutation zone to the next. At the point of commutation this flux is reversed in direction with respect to the armature conductors, and, therefore, there will be local currents set up in the armature copper itself, due to this action. This, however, should be more properly charged to commutation loss rather than to armature core loss.

The above covers the principal core losses in direct-current machines. It was the original intention to analyze the core losses in the various types of rotating machines, but it soon developed that the subject was too extensive for the scope

of this paper, therefore it was limited to d-c. machines only. However, many of the conditions which hold for d-c. machines also apply, to a certain extent, to many other types. In addition there are losses in d-c. machines which are relatively large compared with those in other apparatus, due to the fact that the tooth saturation in d-c. machines is frequently carried much higher than in other apparatus.

The foregoing treatment of core losses is qualitative rather than quantitative, and it deals with the simpler phenomena only. It omits some very complex conditions, such as the effect of pulsations in flux superposed on high densities, displaced minor hysteresis loops, etc., which mean additional losses. The principal object of the paper is to give a better idea of the possibilities and impossibilities of the problem of core losses.

To be presented at the 319th meeting of the American Institute of Electrical Engineers, New York, March 10, 1916.

(Subject to final revision for the Transactions.)

THE INFLUENCE OF FREQUENCY OF ALTERNATING OR INFREQUENTLY REVERSED CURRENT ON ELECTROLYTIC CORROSION

BY BURTON MCCOLLUM AND G. H. AHLBORN

ABSTRACT OF PAPER

This paper describes experimental work done to determine the co-efficient of corrosion of iron and lead in soil with varying frequencies of alternating or reversed current with 60 cycles per second as the highest frequency and a two-week period as lowest—some d-c. tests being made as a check on the methods. The results show (1), that a decrease of corrosion occurs with an increase in frequency; (2), that the corrosion is practically negligible below a five-minute period; (3), that there is, a limiting frequency above which practically no corrosion occurs; (4), that certain chemicals affect the natural and electrolytic corrosion of the two metals quite differently; (5), that the loss of lead in soil on direct current is about 25 per cent of the theoretical loss; and (6), that alternating or reversed current with as long periods as a day or a week would in the case of iron materially reduce the damage to underground structures.

The importance of these results grows out of the fact that there are large areas in practically every city in which the polarity of the underground pipes reverses with periods ranging from a few seconds to an hour or more due to the shifting of railway loads. The investigation shows that the corrosion under such conditions is much less than has generally been supposed.

I. INTRODUCTION

THE TERMS "electrolytic corrosion" and "electrolysis" have been used to designate corrosion caused by the discharge of electric currents which entered the metal from outside sources. In this paper the term a-c. electrolysis applies not only to electrolysis from ordinary alternating currents of commercial frequencies, but also to alternating currents of much longer periods, such as several minutes or even a day or longer. Alternating currents of such long periods are very common on portions of underground pipe systems of practically every city due to the continual shifting of railway loads which causes the pipes within a large area, commonly called the neutral zone, to continually change their polarity with respect to the earth. In this paper the term "coefficient of corrosion" is frequently used in connection with the corrosion

Manuscript of this paper was received January 27, 1916.

of an anode. This factor is the ratio of the actual corrosion observed to that which would have occurred if all of the electrode reactions determined by Faraday's law had been involved solely in corroding the anode. Thus if the theoretical corrosion in any case was 100 grams and the observed corrosion 46 grams, the "coefficient of corrosion" would be 0.46. This is sometimes called "efficiency of corrosion."

Importance and Scope of the Present Investigation

Since most of the electrolysis which occurs is due to stray currents from electric railways, and since only a small percentage of these operate with alternating current, it might seem at first thought that a-c. electrolysis is of rather infrequent occurrence, and that the problems connected with it do not deserve much attention. However, in addition to the railways which use alternating or reverse currents as motive power, such currents often result as an incident of railway operation. These occur not only in the ordinary negative systems of railways as mentioned above, as the trolley load shifts from point to point on the track with the movement of the cars, but they occur to a greater extent and in a much larger territory in the case of negative return systems in which insulated negative feeders are used. In such systems the potential differences between pipes and tracks can be greatly reduced, but this is accompanied by a large increase in the area of the so-called neutral zone in which the polarity of the pipes is continually changing from positive to negative. With certain types of three-wire systems which are now being seriously considered in some places for the prevention of electrolysis, there will be large areas in which the polarity of the pipes will fluctuate between small positive and negative values. It has also been proposed that with the usual type of return that the trolley be made alternately positive and negative on succeeding days or weeks. All of these methods would have the effect of reversing the current flow on underground structures, and the period of the cycle would vary from a few seconds to a day or longer. Moreover, the frequent grounding of 60-cycle lighting circuits permits a certain amount of leakage from those systems, and the corrosion produced, especially in case of accidental grounds on other parts of the system, is of considerable importance. It is therefore of great practical importance to determine the extent to which periodically reversed currents

of these long periods will produce corrosion on subsurface metallic structures.

Work of Previous Investigators

A number of writers have advanced theories concerning laws governing a-c. electrolysis and a considerable amount of experimental work has been done with frequencies of 25 to 60 cycles. One writer, discussing the phenomenon from the standpoint of the decomposition of the electrolyte,[1] arrives at certain conclusions: (1), That the quantity of electrolyte decomposed by alternating current is less than by direct current; (2), that it is proportional to the electrode current density; (3), that there is a limiting electrode current density below which no decomposition of the electrolyte occurs; (4), that the quantity decreases with an increase in the frequency of alternations, and that there is a limiting rapidity of alternation above which there is no decomposition. Conclusions (1), (3), and (4) seem borne out by the experimental work described later.

With reference to the dynamic characteristics of electrolytic cells, several writers have determined by experimental work,[2] chiefly with the oscillograph, that such cells affect the wave form. As one writer states, the chemical polarization in the cell causes it to behave as a variable condenser with a resistance in parallel and in series.

With a very special set of conditions one experimenter[3] has noted an amount of corrosion of the electrodes varying from zero to 35 per cent, with 60-cycle current, and he arrives at the conclusion that the corrosion is practically independent of the current density of the electrodes and temperature; and also that stirring of the solution has no effect. He states that the corrosion does depend on the condition of the electrode surface but does not attempt to state the principle of this variation.

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1. Dr. Guglielmo Mengarini, *Electrical World*, Vol. 18, No. 6, p. 96., Aug. 8, 1891.

2. Ruchinstein, D. Electrolysis with Alternating Current Dynamic Characteristic of an Electrolytic Cell. *Zeitschrift für Electrochemie* December 1, 1909; LeBlanc, M. The e.m.fs. of Polarization and their Measurement by the Oscillograph. Deut. Bunsen Geselschaft. No. 3. Alternating Current Electrolysis Use of Oscillograph in Connection with Polarization. *Zeitschrift für Electrochemie* 11, 707, 1905.

3. White, G. R., Alternating Current Electrolysis with Cadmium Electrodes.

Experiments of more practical importance to the engineering world were conducted in 1905.[4] Twenty-five-cycle current was impressed on iron and lead pipes buried in soil and it was found that the corrosion was practically the same as that due to the soil alone. No figures of exact losses are given. Alternating current of 25-cycle frequency was impressed on lead and iron plates in salt solution and direct current was impressed on other plates in a similar electrolyte and it was found that the loss was negligible for the alternating current and very large for the direct current.

Only a year or so later a large number of tests were conducted with 25-cycle, 60-cycle, and direct current on iron and lead plates.[5] The conditions were varied by using different soils, salts added to soils, varying the temperature and current density. The results show that although there is quite a large variation in the loss with different specimens and that the 25 cycle losses are uniformly greater than the 60-cycle; these losses never exceed one per cent under normal temperature conditions. The writer notes that some salts, for example, carbonates and alkaline compounds, reduce the electrolytic corrosion of lead plates. He found that an increase of temperature to 40 deg. cent. increases the corrosion to about one per cent. His final conclusions are that a-c. electrolysis is more irregular than d-c. electrolysis, that nitrates increase corrosion and carbonates generally decrease it, but that the effect is not great enough to be of practical use for protecting lead cables; that lead is more readily attacked than iron; that the current density does not appreciably affect corrosion except indirectly by increase of temperature; and that the corrosion increases with a decrease in frequency. He attempts to protect lead specimens by making them negative either by connecting them to a zinc plate or with a small direct current, and finds that the loss is considerably less than with the alternating current alone. He finds that a current of one per cent of the value of the alternating current is sufficient to give practically complete protection, the corrosion in some instances being less than that due to natural corrosion alone. It will be noted in the above experimental work that the different variables employed, such

4. Kintner, S. M., Alternating Current Electrolysis, *Electric Journal*, Vol. 2. p. 668, 1905.

5. Hayden, J. L. R., Alternating Current Electrolysis, TRANS. A. I. E. E., Vol. 26, Part I, p. 201.

as current density, chemicals, temperature, etc., do change the action of alternating current, but that in practically no case did the losses exceed one per cent. When we consider the large variation of the electrochemical loss produced by direct current under identical conditions, it is evident that differences obtained between 25- and 60-cycle current are practically negligible.

Purpose of this Paper

The data discussed in this paper were obtained as a part of the general investigation of electrolysis conducted by the Bureau of Standards. Its object is not to determine the laws which govern electrolytic corrosion at any one frequency, but to take a standard set of conditions approaching as nearly as possible those existing in practise, that is, wrought iron pipes and lead sheaths imbedded in soil and to determine the corrosion which will occur in the range of frequencies mentioned above, namely, for frequencies ranging from 60 cycles per second to a week or more per cycle. These data will be of material assistance in determining the effectiveness of many of the proposed systems of electrolysis mitigation.

II. DISCUSSION

Preliminary Experiments on Effect of Circulation of Electrolyte

Before beginning the more complete series of tests to determine the effect of change in frequency, a number of preliminary experiments were carried out in order to throw light on certain theoretical aspects of the question under consideration. Theoretical considerations led to the belief that the corrosion of frequently reversed currents would be materially increased by rapid circulation of the electrolyte and diminished by conditions which tended to restrict such circulation. If this were true it was reasoned that in the case of metals buried in soils, in which the circulation of electrolyte is greatly restricted relatively little corrosion would occur even with periodically reversed currents of long period. Accordingly a number of experiments were carried out to determine the effect of circulation of the electrolyte on the coefficient of corrosion.

A set of four cells with wrought iron electrodes and a one per cent NaCl solution as the electrolyte were connected in series on 60-cycle current. The electrolyte in cell No. 1 (see

Fig. 1) was stirred by a small turbine and in No. 2 the electrolyte was undisturbed; in No. 3 the electrodes were wrapped with filter paper; and in No. 4 the electrolyte was gelatin. Iron electrodes which were carefully weighed were connected in the circuits and the current was maintained at about a

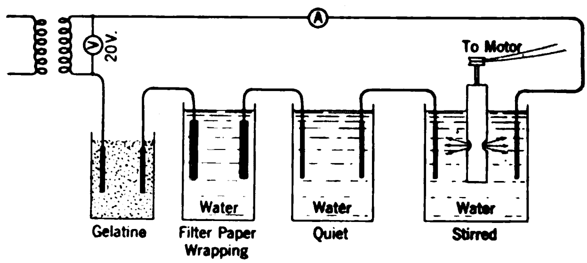


FIG. 1—ARRANGEMENT OF FOUR CELLS

half ampere for nearly 200 hours. At the end of the run the electrodes were again weighed and the loss determined by difference from the initial weight. Based on the theoretical loss, which would have been about 100 grams, the coefficients of corrosion (see Table I) are 0.0034 for the stirred electrolyte;

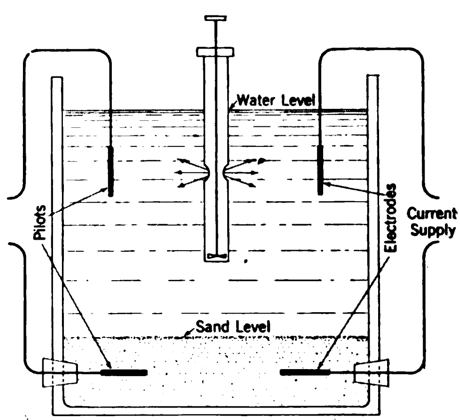


FIG. 2

0.002 in the stationary solution; 0.0009 when protected by filter paper; 0.0007 in the gelatin. It seems evident that the chemical action is not as reversible when the electrolyte is in motion about the electrodes as when stationary. In order to determine this effect more exactly a single cell was con-

nected as shown in Fig. 2. Here there were two electrodes with no current impressed to determine the natural corrosion and two serving as current electrodes. One of these was in the electrolyte stirred by the turbine and the other was wrapped in filter paper and buried in sand saturated with the solution. After correcting for the natural corrosion it was found that the

TABLE I.
VARIABLE—STATE OF ELECTROLYTE.
60-Cycle Current
Wrought Iron Electrodes
1 per cent NaCl Solution Electrolyte

State of electrolyte	Total corrosion grams	Current ampere-hours	Coefficient of corrosion
Stirred	0.344	96	0.0034
Stationary	0.202	96	0.0020
Filter paper, separation	0.088	96	0.0009
Gelatin	0.074	96	0.0007
Stirred	0.065	160	0.0004
Sand saturated	0.016	160	0.0001

TABLE II.
VARIABLE—STATE OF ELECTROLYTE.
20-Cycle Current
Wrought Iron Electrodes
1 per cent NaCl Solution Electrolyte.

State of electrolyte	Total corrosion grams	Current ampere-hours	Coefficient of corrosion
Stirred	0.079	144.4	0.0005
Sand, saturated	0.009	144.4	0.00006

coefficient of corrosion was 0.0004 for the upper electrode and 0.0001 for the lower. The results are shown in Table I. The same type of cell was operated on 20-cycle alternating current with the losses as shown in Table II. It will be noted that the loss values are almost exactly the same as those on 60 cycles under the same conditions and in every case are considerably less than 0.005. The same type of cell was placed in a d-c. circuit which was reversed every 24 hours. As might be ex-

pected, the losses were very much greater, as shown by Table III; although the number of ampere-hours was considerably less than that used in the previous experiments. The electrode surrounded by the moving solution had a loss corresponding to a coefficient of corrosion of 0.45, while the other gave 0.32, the difference due to stirring thus being even more evident on the slow reversals than on the high frequencies. If only the current discharged by each electrode as anode were considered, the coefficient of corrosion in the stirred solution was 0.90, and that in the confined electrolyte was 64 per cent.

TABLE III.
VARIABLE—STATE OF ELECTROLYTE.
24-Hour Reversals
Wrought Iron—Electrodes
1 per cent NaCl Solution Electrolyte.

State of electrolyte	Electrolytic corrosion grams	Current ampere-hours	Coefficient of corrosion
Stirred	45.45	97.1	0.45
Sand, saturated	32.45	97.1	0.32

The foregoing results show that the free circulation of the electrolyte has a pronounced effect on the coefficient of corrosion, and that this effect is greater the lower the frequency of the current. They show that the low corrosion coefficient on alternating current is not determined solely by the speed of the reactions and the frequency of alternations. A more probable explanation is that the corrosion during any half cycle in which the electrode is anode takes place in accordance with Faraday's law, as in the case of direct current, but that during the succeeding half-cycle when the electrode is cathode a large part of the corroded metal is electroplated back on the electrode. The increased corrosion due to circulation of the electrolyte would be expected under this theory, since the convection currents in the liquid would carry away from the electrode surface a part of the metal that has been corroded during the half of the cycle when the electrode is anode thus preventing as complete a redisposition during the succeeding half-cycle as would otherwise occur. In particular these convection currents in the electrolyte would bring into contact

with the metallic ions, oxygen or other chemicals which would tend to form insoluble compounds, thus rendering the corrosive process irreversible.

Accepting the above theory, we would expect that in the case of iron or lead buried in soils, in which circulation of the electrolyte is greatly restricted, the corrosive process would be in large degree reversible even with much longer periods of reversal than in the case of liquid electrolytes, and it seemed possible that this condition might prevail even where the period of the cycle is several minutes or longer, as in the case of the polarity of buried pipes in many localities as mentioned above. This was found to be actually the case, as the following described experiments show.

Complete Series of Tests

(*a*) ***Arrangements.*** With the results of the above experiments in view a more complete series of tests was planned. Since there is considerable variation among individual specimens it was recognized that quite a number of specimens under each frequency would be necessary in order to get a fair average. The specimens were arranged in cells having two current-carrying electrodes and one specimen subjected only to soil corrosion, this specimen being protected from the flow of current by a glass cyclinder as shown in Fig. 3. In a few cases the effect of adding sodium carbonate to the soil was studied. For convenience the greater part of the tests were made in jars in the laboratory, but a number were made in specimens buried in soil out of doors in order to check the results obtained in the laboratory. The agreement between the results under the two conditions was found to be satisfactory. The entire series is outlined in Table IV.

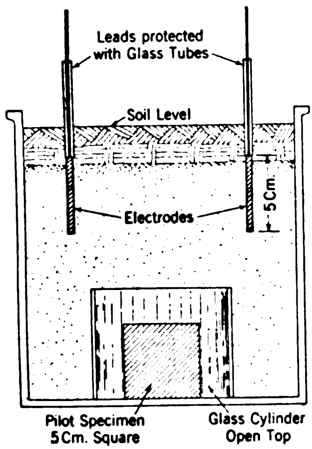


Fig. 3

(*b*) *Electrolyte.* In determining the coefficient of corrosion with different frequencies of current reversal it is desirable to simulate operating conditions as nearly as is feasible in a complete and general test. For this reason soil was selected

as the electrolytic medium rather than water which contains the soluble constituents found to exist in soil by chemical analysis. Conditions of circulation of the electrolyte and the electrolytic transfer in it are very different than in soil. The soil used was natural soil near the Bureau of Standards—a light clay having a resistance of 8000 ohms per centimeter cube at approximate saturation. It will support a good vegetable growth and is a fairly normal soil. Soil from the same locality

TABLE IV.
SUMMARY OF TESTS.
a. Dimensions of Electrodes.

Electrodes	Indoor	Outdoor
Iron	5 x 5 x 0.5 cm.	20 x 20 x 0.2 cm.
Lead	5 x 5 x 0.2 cm.	15 x 15 x 0.4 cm.

b. Frequencies Used and Number of Specimens Used for both Iron and Lead.

Frequency of reversal	Number of specimens		
	Indoor		Outdoor Tests
	Natural Soil	Soil with Na_2CO_3	
60 cycles per sec.	18	18	3 large } Iron only.
15 cycles per sec.	18		
1-sec. cycle	18	18	3 " } Iron only.
6-sec. cycle	18		
1-min. cycle	18		
5-min. cycle	18		
10-min. cycle	18	18	
1-hr. cycle	18		
2-day cycle	18		
2-week cycle	18	18	
Direct current	18	18	3
Totals	198	90	9 large

Grand total for iron 297
" " " lead........291
" " " all tests.....588

was used in the experiments described in a previous Bureau of Standards report[6] and a coefficient of corrosion of 100 obtained on iron at a definite current density.

(*c*) *Conditions of the Tests.* Some of the tests were run in the soil out of doors with natural drainage and aeration. Although it was considered very desirable to make a number of such tests, to run a complete series in outside soil would

6. McCollum and Logan; Technologic Paper No. 25. Electrolytic Corrosion of Iron in Soils.

have been very difficult on account of interference by weather, difficulty of getting electrical connections to many electrolytic cells, and especially the insulating of the various sets from each other, which would be necessary in order to determine the current actually entering or leaving each specimen. The cells used in the inside laboratory tests were 1-gal. (3.8-liter) earthenware jars filled with soil to about 3 cm. from the top (about 3 kg.) kept practically saturated by adding a quantity of distilled water every day. The tops were left open that evaporation and aeration might go on in a normal way.

(*d*) *Chemicals.* Since some soils vary widely in chemical constituents and these may have a pronounced effect on the rate of corrosion, it seems desirable to vary those constituents in the soil which may be expected to affect the corrosion. As indicated by preliminary tests, sodium carbonate (Na_2CO_3) has a very considerable effect on the electrolytic corrosion of both iron and lead; moreover sodium is a common element in soil, as are carbonates; and this combination is quite soluble, which makes it a satisfactory compound to use in the soil, 0.5 per cent being added to certain cells, as shown in Table IV.

(*e*) *Electrodes.* Since iron and lead are the two metals commonly serving as underground electrical conductors exposed to soil they were selected as the materials for specimens in these tests. The above mentioned report[6] shows that the corrosion of different kinds of iron does not differ by large percentages under the conditions of these tests, and since "American iron," which is Bessemer process steel, is obtainable in convenient form it was adopted. This material was fine-grained and quite pure, having about one-tenth per cent carbon and no slag. The lead was commercially pure and on analysis was found to contain traces of tin or antimony. Indoor specimens were 5 by 5 cm. square, the iron being about 0.5 cm. thick and the lead 0.2 cm. thick. The outdoor iron specimens were 20 cm. square and about 0.2 cm. thick.

The mill scale and oxide left on the materials in the process of manufacture were not removed, since it was felt that with alternating current the surface might affect the corrosion considerably more than with direct current. The leading-in wire was soldered to a corner of each specimen and a number stamped on the same corner. It was then weighed and a glass tube put over the lead and the tube was then sealed with pitch and the lead attachment and number covered with the same

material. This type of connection failed in very few instances due to corrosion and the tube and pitch were easily removed with toluol before the specimen was reweighed.

(*f*) *Frequency*. In determining the frequency of reversal of current two things must be considered: first, the frequencies found in practise; and second, the completeness of the series so that a suitable curve could be obtained showing the relation between the corrosion coefficients and the frequency of reversal of current. The standard lighting frequency, 60 cycles is available, and 15 cycles adopted as about the lowest frequency proposed for power work. To obtain the slow reversals a reversing commutator machine was built which is described in detail later. It gave periods of one second, 6 seconds, 1 minute, 5 minutes, 10 minutes, and 1 hour. The short periods of reversal were adopted because reversals of polarity of such frequencies commonly occur in the usual operation of a street railway system as pointed out above. Daily and weekly reversals and d-c. tests were also made. The d-c. specimens serve as a check on the theoretical coefficient of corrosion.

(*g*) *Current Density*. The current density flowing to or from the plates was intended to be such as to produce approximately 100 as the coefficient of corrosion with d-c. electrolysis. This is shown in Technologic Paper No. 25 of the Bureau of Standards above referred to, to be about 0.5 milliampere per sq. cm. for iron and approximately this value was used on both the indoor and outdoor specimens.

(*h*) *Length of Run*. The tests were contined until enough effect was produced to permit of accurate determination of the differences in weight of the specimens before and after test. It was also intended that one of the tests should be continued until a state of equilibrium was reached in the cell; that is, until the rate of corrosion was not changing rapidly as might be the case during the first few cycles of current. Moreover, the cells should not be run to an exhaustion of the soluble chemicals, their concentration being probably closely related to the amount and rate of corrosion occurring on the electrodes. Since the current density is the same in all cases, this rate will depend on the frequency of reversal, and since the coefficient of corrosion is less on the higher frequencies these must run fully as long as the lower frequencies in order to obtain sufficient weight differences. A period of 15 to 20

days has been found to produce sufficient differences in weight, and no indication that the composition of the soil except that very close to the electrodes had been changed decidedly.

(*i*) *Accidental Variables.* Other possible variables that received attention during the experiments were maintained as nearly constant as possible. The temperature did not vary widely from 20 deg. cent. there being very little heating by the current at the voltage and current density used. The depth was maintained about 10 cm. below the surface in the indoor tests and about 40 cm. in those outside the laboratory.

(*j*) *Cleaning Electrodes.* After each run was completed it was necessary to remove the end products of the corrosion process, and since they adhered firmly in some cases special methods were necessary. Iron specimens were cleaned by making them cathode on a ten volt circuit in a two per cent sulphuric acid solution, as described in Technologic Paper No. 25 of the Bureau of Standards. This was found to be very effective and did not attack the iron enough to show on the balances used. The lead specimens were cleaned by immersing them in a solution containing 5 per cent oxalic acid and 1½ per cent of nitric acid. The corrosion products became lead oxalate—a white flocculent substance which was easily removed by brushing. It was found in some cases where the amount of corrosion was large and adhered very firmly that this process was very slow and did not remove the corroded products entirely. Unoxidized specimens weighed before and after immersion in this lead cleaning solution were found to have lost less than 5 milligrams, the limit of the balances used.

Equipment

(*a*) *Current Sources.* Sixty-cycle current was obtained from the city power mains, while the 15-cycle current came from a small inverted synchronous converter. Transformers were used in both circuits to raise the voltage so that a number of cells could be operated in series and so that the primary side would be clear of ground. For the slower reversals of current on the indoor tests power was obtained from the regular three-wire lighting busbar and commutated by the machine described below. For the outdoor tests for slower reversals and for direct current a small motor-generator set was used. A no-current indicator was used on the a-c. circuits while a recorder showed what had occurred on the d-c. circuit and those f long period at all times.

(*b*) *Commutating Machine.* The commutating machine through which the intermediate frequencies were obtained consisted of a series of six commutators each having four brushes and two equal semi-circular commutator segments, giving two complete cycles per revolution, driven by gears having such ratios that with the first or highest speed commutator rotating once in two seconds the succeeding commutators made complete current cycles in six seconds, one minute, five minutes, ten minutes, and one hour. This machine was driven by a constant speed motor.

(*c*) *Resistance.* In order to obtain the correct current density discharged from the electrodes the resistance of the circuits had to be varied. This was done in part by placing cells in series in groups and paralleling these groups. Rheostats or tungsten lamps were then used to get final adjustments, but no great effort was made to keep the current discharge at exactly 0.5 milliamperes per sq. cm., since a small variation in current density does not affect the rate of corrosion. Tungsten lamps with their high positive temperature coefficient are very satisfactory for use in such circuits, since within a certain range they tend to automatically maintain the current at a constant value.

(*d*) *Current Measurements.* Observations of current were made every day, and more frequently when the current values were changing appreciably. A standard milliammeter having a resistance of 0.34 ohm was used for all frequencies above one second. For a-c. measurements a thermoammeter consisting of a heating element, thermocouple and millivoltmeter was used. The resistance of this meter amounted to about 7 ohms, and was non-inductive. When this meter was introduced in circuits the effect on the current flow was negligible because of the high resistance of the circuits and it was very easy to correct for this small non-inductive resistance by inserting an equal amount in each circuit when the meter was not in use. This meter was used to measure larger current in the outdoor specimens by means of a shunt. A suitable ampere-hour meter was not available.

Correction and Reduction Factors

Since chemical corrosion, according to Faraday's law, is proportional to the average current flowing, and since all a-c. values as observed are effective values rather than average,

the current flow has been corrected by dividing the same by 1.11, the ratio between effective and average values of sine-wave current. Since the current flowing with the longer time reversals is controlled by a commutating machine or switch the wave is flat-topped and no such correction is necessary. However, the current was off when controlled by the commutating machine, 6 or 7 per cent of the time and this correction was applied to all such values. In order to correct any error due to a possible difference in the length of succeeding ½ cycles, the connections to the commutator controlling each test were reversed at regular intervals, *e.g.*, the one-second commutator was reversed through the 10-minute commutator and the one-hour one by a switch every 24 hours. In calculating the theoretical amount of corrosion, the corrosion products of both iron and lead were taken to be divalent and the quantity corroded per ampere-hour is then 1.04 grams for iron and 3.86 grams for lead.

Accuracy of Results

The accuracy which can be obtained in corrosion experiments of this kind is limited by a number of factors; first, the consistency of the corrosion action itself, which it has been found may vary within wide limits under apparently similar conditions; and second, the limits of measurement. The electrical measurements are correct to about one per cent while the time measurements are not in error more than a half per cent. The error due to weighing of single specimens was small, since it was carried to the fourth or fifth place, but in some cases the losses were small and this difference was correct to only the second or third place. This is true of practically all pilot specimens which were subjected only to natural corrosion. Therefore it is evident that the accuracy of the results is greater when the amount of corrosion is large. The combined accuracy of all measurements was much greater than the consistency to be expected in the corrosive processes.

Description of Each Run

The above description of the general condition of the tests is intended to apply to all the following data, and it will be necessary to describe each run only very briefly, deferring until later the presentation of the results.

(*a*) *Sixty-Cycle Tests*. The 60-cycle tests were run with both iron and lead specimens on the indoor tests and iron f r

the outdoor tests. Both natural soil and soil with 0.5 per cent sodium carbonate added were used for the indoor tests. It will be noted from the tables presented in this as well as in other runs that the natural corrosion losses have been rather large on the iron pilot specimens. This is due to the fact that the mill scale was not removed from these specimens before the tests were started and that the cleaning process removed this scale as well as the oxide that was formed during the test. This rather obscures the comparative effect of natural soil and sodium carbonate, but it is still evident as in the earlier tests that the natural corrosion loss of iron is greater in natural soil while the electrolytic corrosion is greater in the chemical soil. In fact in almost every instance the natural loss was greater than the electrolytic loss in the natural soil, and in five of the twelve specimens also in the chemical soil. With the three large specimens used in the outdoor tests the natural loss was considerably less than the electrolytic loss, and the coefficient of corrosion is only slightly less than one per cent.

(*b*) *Fifteen-Cycle Tests.* The 15-cycle tests were run with lead and iron in soil only, these cells being in series with about 310 volts, giving about 25 volts per cell. In every case except four iron electrodes the electrolytic losses were all greater than the natural corrosion in the same cells.

(*c*) *One-Second Period.* Iron and lead specimens in both normal soil and soil with sodium carbonate were used in the tests with one-second period, the cells being divided into four groups of three each in series. In two cases the iron electrodes lost more than the pilot specimens but on the average the losses were greater than in the preceding tests. Iron specimens were placed in outdoor soil for these tests, and in this instance the natural corrosion is unusually high because the specimens were left in the ground without current for a considerable time.

(*d*) *Six-Second Period.* Normal soil alone was used in these tests, there being three groups of cells and four cells in each group. Approximately 12.5 volts existed across each cell in order to maintain the current at about 30 milliamperes or 0.5 milliamperes per sq. cm.

(*e*) *One-Minute Period.* In the one minute reversals iron and lead electrodes were used in natural soil connected in three groups of four cells each. Approximately nine volts were maintained across the cells containing the iron electrodes and 14 volts on the lead electrodes. In case of the iron elec-

trodes there was a consistently greater loss on the odd electrode than on the even; the reason for which is not altogether evident since no such consistency exists on the lead specimens; and as the two sets were in series, it is therefore not due to unbalanced or unequal half cycles.

(*f*) *Ten-Minute Period.* Both iron and lead specimens in natural soil and soil containing sodium carbonate were used in the ten-minute period tests. The cells were divided into four groups of six each. It will be noted that the corrosion of iron in natural soil is here greater than in the chemical soil and the reverse is the case with the lead specimens.

(*g*) *One-Hour Period.* Only natural soil was used in the one-hour reversals, about 15 volts being impressed on each pair of electrodes.

(*h*) *Forty-Eight-Hour Period.* Natural soil alone was used in the daily reversals (48-hour period) with iron and lead electrodes, the entire set being in series on 240 volts. The iron specimens had a voltage of about 15 volts on each pair and the lead electrodes about 13 volts. In the case of the iron specimens the odd and even specimens, or those anode first or anode last in the test show no great or consistent difference as noted in the preliminary tests, and the lead specimens show an opposite effect from that noted at that time, that is, the electrodes which were anode during the first half-cycle have lost more than those which were cathode initially.

(*i*) *Weekly Reversals.* Both natural soil and soil containing sodium carbonate were used in the weekly reversals (2-week period) and the entire set was connected in series on 240 volts. The voltage across the iron specimen cells in the natural soil was about 15 volts per cell and about 9 volts in the chemical soil. With the lead electrodes the average voltage was less than 12 across each cell in the natural soil and less than 4 in the chemical soil.

(*j*) *Direct-Current Tests.* The d-c. tests were carried on with iron and lead specimens both indoors and outdoors and in the indoor tests with sodium carbonate in the soil as well as natural soil. The indoor cells were connected in four groups of six each with 230 volts impressed on them. The ampere-hours varied in the different groups from eight to twelve. With the iron specimens the anode losses are large, the coefficient of corrosion being approximate unity, while the cathode specimens lost less than the pilot specimens, evidently because of

the protective effect of the current. In the lead specimens, however, the anode losses are far below what might be theoretically expected, while the cathodes lost less in the natural soil than the pilot specimens but more in the soil containing sodium carbonate. This is due not so much to an increased electrolytic loss in the chemical soil, but to a greatly decreased natural loss. Since the loss in the lead specimens was so much less than might be expected another set was run under practically the same conditions but with the current maintained more closely at 0.5 milliampere per sq. cm. These results, however, corroborate the work previously done. The outdoor tests were conducted on both lead and iron with the large plates mentioned above. The protective effect of the current is noted again on the iron specimens. With the lead specimens no cathodes were used, it being desired simply to check the anode corrosion which on all the indoor tests had been so small. Twelve anodes were used, the lead in this case being sections of lead sheath cable, six of which contained about one per cent antimony while the other six contained only traces of tin and antimony. Two pilot specimens of each composition were used. These tests further corroborated the results of the indoor tests in that the coefficient of corrosion of lead on direct current was low.

Discussion of Results

Tables containing the summary of the results of the above mentioned tests are given. These tables are arranged in halves with losses in grams above and the coefficient of corrosion below with the frequency or period of reversal in the first column, the average loss of six specimens in each of the three succeeding columns (the first being the odd numbered electrodes and the second the even numbered electrodes and the third the pilot specimens.) From these are calculated the electrolytic loss of odd or even electrodes shown in the fifth and sixth columns, and the seventh column contains the average electrolytic loss of all electrodes. Below the frequency is repeated and the next column contains the average quantity of electricity in ampere hours flowing through the specimens. Following this are four columns giving the coefficient of corrosion. The coefficients of corrosion of the odd electrodes and even electrodes are first given, then the coefficient of corrosion based on one-half the current or that while each electrode was positive, and last, that based on the average loss and the total current

through the cells. Since it is difficult to draw any conclusions from the electrode losses shown without also considering the ampere-hours, the coefficients of corrosion will give us the best

TABLE V

SUMMARY OF ALTERNATING-CURRENT ELECTROLYSIS TESTS—I.

Variable—Frequency of Reversal.

Indoor Tests
Iron Electrodes
Soil Electrolyte.

Period	Total loss: Odd electrodes	Total loss: Even electrodes	Total loss: Pilot	Electrolytic loss: Odd electrodes	Electrolytic loss: Even electrodes	Electrolytic loss: Average
	Grams	Grams	Grams	Grams	Grams	Grams
60 cycle	1.480	1.289	1.645	−0.165	−0.356	−0.261
15 cycle	1.036	0.862	0.834	+0.202	+0.028	+0.115
1 sec	1.064	1.190	0.640	0.424	0.550	0.488
6 sec	0.960	1.046	0.566	0.394	0.480	0.437
1 min	2.024	2.077	1.203	0.821	0.874	0.848
5 min	1.907	1.398	0.748	1.159	0.650	0.904
10 min	2.522	2.252	0.901	1.621	1.351	1.486
1 hour	3.134	2.941	1.165	1.969	1.776	1.872
2 days	5.490	5.124	1.130	4.360	3.994	4.177
2 weeks	8.349	9.680	1.387	6.962	8.293	7.627
D. C.	9.697	0.139	1.023	8.674		8.674

Period	Current discharge ampere-hrs.	Coefficient of corrosion: Odd electrodes	Coefficient of corrosion: Even electrodes	Coefficient of corrosion: Average ½ current	Coefficient of corrosion: Average total current
60 cycle	16.05	−0.0198	−0.043	−0.031	−0.0156
15 cycle	13.32	+0.0292	+0.0004	+0.016	+0.008
1 sec	17.99	0.045	0.059	0.046	0.023
6 sec	16.83	0.045	0.055	0.050	0.025
1 min	19.25	0.082	0.087	0.084	0.042
5 min	19.99	0.111	0.063	0.087	0.043
10 min	16.48	0.189	0.158	0.173	0.087
1 hour	18.40	0.206	0.186	0.197	0.098
2 days	27.22	0.308	0.282	0.295	0.148
2 weeks	23.17	0.58	0.69	0.633	0.316
D. C.	9.82	0.85			0.850

idea of results, and these are shown in both the tables and curves.

(*a*) *Indoor Tests. Iron in Normal Soil.* In Table V a summary of the results obtained using iron electrodes in indoor

cells containing normal soil are given. As mentioned earlier, it will be seen that the pilot specimen loss is quite large and that there is considerable variation under the different frequencies. This is evidently a real variation due to a difference in soil action because it was found that in individual cases when the pilot specimen corrosion varied considerably from the average the current-carrying electrodes would also vary in the same direction. The coefficient of corrosion only in the case of the 60-cycle tests is negative. The electrodes were numbered consecutively, an odd number and a succeeding even number being grouped in each cell. The difference in the coefficient of corrosion between the odd and even electrodes is rather large in some cases; for example, in the 5-minute specimens the coefficient is 0.111 for the odd electrodes and only 0.063 for the even and in the 15-cycle test, the per cent discrepancy is large although the values in grams do not differ greatly. The d-c. test shows a coefficient of only 0.85 which is rather low, and this can only be explained as being probably due to the effect of the iron oxide serving as a protection rather than accelerating the corrosion. The next to the last column is simply double the one succeeding or an average of the odd and even electrode coefficients.

(*b*) *Indoor Tests. Iron Electrodes in Soil with Sodium Car bonate.* In Table VI containing the results on iron electrodes in sodium carbonate soil it will be noted that in the case of the 60-cycle run the coefficient of corrosion is positive but that the values in the other cases of reverse currents are smaller than in the natural soil. In the two-weeks test the odd-electrode loss is considerably less than the even, supporting the theory that in these longer time reversals the electrodes which are positive last suffer the greater loss. Under these conditions the d-c. loss is very nearly 100 per cent.

(*c*) *Indoor Tests. Lead Electrodes in Soil.* With lead electrodes in soil very regular results were obtained. In Table VII the loss is shown to be increasing gradually from 60 cycles to 2 weeks with only one discrepancy, the even electrode in two-day reversals being considerably smaller than on the 10-minute and 1-hour specimens. The products of corrosion seem to be increasing the effect on the pilot specimens, as it will be noted that the loss is increasing as the frequency decreases. However, the most remarkable facts concerning these tests is that the odd electrodes, those which were initially

positive in the tests, lost considerably more than the even electrodes in both the two-day and two-weeks test. The other remarkable feature is the small coefficient of corrosion exhibited in the case of the d-c. test. Since in the first set weighed the losses were so small, (only 22 per cent of the theoretical) a second run was made and a coefficient of 0.25 obtained, prac-

TABLE VI.
SUMMARY OF ALTERNATING-CURRENT ELECTROLYSIS TESTS—II.
Variable—Frequency of Reversal.

Indoor Tests
Iron Electrodes
Soil and Sodium Carbonate Electrolyte.

Frequency of reversal	Total loss			Electrolytic loss		
	Odd electrodes	Even electrodes	Pilot	Odd electrodes	Even electrodes	Average
	Grams	Grams	Grams	Grams	Grams	Grams
60 cycle	1.390	1.373	1.199	+0.191	0.174	+0.182
1 sec.	0.865	1.146	0.677	0.188	0.469	0.329
10 min	1.617	1.532	0.835	0.782	0.679	0.739
2 weeks	7.922	9.081	1.636	6.286	7.451	6.868
D. C.	10.423	0.172	0.819	9.604		9.604

Frequency of reversal	Current discharge ampere-hrs.	Coefficient of corrosion			
		Odd electrodes	Eeven electrodes	Average ½ current	Average total current
60 cycle	16.05	0.023	0.021	0.022	0.011
1 sec.	17.99	0.020	0.050	0.035	0.018
10 min	16.48	0.091	0.081	0.086	0.043
2 weeks	23.17	0.52	0.62	0.57	0.285
D. C.	9.82	0.94			0.94

tically the same as before. This indicates that under the conditions of these tests and probably under most soil conditions the corrosion of lead is very considerably less than it has been formerly considered to be.

(*d*) *Indoor Tests. Lead Electrodes in Sodium Carbonate.* The losses of lead electrodes in sodium carbonate (Table VIII)

TABLE VII

SUMMARY OF ALTERNATING-CURRENT ELECTROLYSIS TESTS—III.

Variable—Frequency of Reversal

Indoor Tests
Lead Electrodes
Soil Electrolyte.

Frequency of reversal	Total loss			Electrolytic loss		
	Odd elec-trodes	Even elec-trodes	Pilot	Odd elec-trodes	Even elec-trodes	Average
	Grams	Grams	Grams	Grams	Grams	Grams
60 cycle..........	0.325	0.328	0.124	+0.201	+0.204	0.202
15 cycle..........	0.342	0.332	0.133	0.209	0.199	0.204
1 sec............	0.385	0.354	0.118	0.267	0.236	0.252
6 sec............	0.518	0.528	0.098	0.420	0.430	0.425
1 min..........	2.860	2.845	0.652	2.208	2.193	2.200
5 min..........	3.868	3.634	0.406	3.462	3.228	3.345
10 min..........	3.468	3.738	0.341	3.127	3.397	3.262
1 hr............	5.886	5.771	0.901	4.985	4.870	4.928
2 days..........	8.719	5.072	1.357	7.362	3.715	5.538
2 week..........	13.710	7.789	1.176	12.634	6.713	9.674
D. C............	12.319	0.327	0.937	11.382		11.382
D. C............	13.574	0.277	0.882	12.692		12.692

Frequency of reversal	Current discharge ampere-hrs.	Coefficient of corrosion			
		Odd elec-trodes	Even elec trodes	Average ½ current	Average total current
60 cycle..........	16.05	0.0065	0.0066	0.0065	0.0033
15 cycle..........	13.32	0.0082	0.0077	0.0080	0.0040
1 sec............	14.87	0.0093	0.0082	0.0088	0.0044
5 sec............	16.83	0.0129	0.0132	0.0131	0.0065
1 min..........	19.25	0.059	0.059	0.059	0.030
5 min..........	19.99	0.089	0.085	0.086	0.043
10 min..........	14.95	0.108	0.118	0.112	0.056
1 hour..........	18.40	0.140	0.137	0.139	0.069
2 day...........	27.22	0.140	0.071	0.105	0.053
2 week..........	23.17	0.282	0.150	0.216	0.108
D. C............	13.40	0.220			0.220
D. C............	12.93	0.254			0.254

are greater than in the normal soil, th edifference being especially noticeable in the longer reversals and in the d-c. tests. For example, in the weekly reversals, the loss in normal soil was 0.108 while in the sodium carbonate it was 0.172; the d-c. loss has risen from about 25 per cent to 34 per cent.

TABLE VIII.

SUMMARY OF ALTERNATING-CURRENT ELECTROLYSIS TESTS—IV.

Variable—Frequency of Reversal

Indoor Tests
Lead Electrodes
Soil and Sodium Carbonate Electrolyte.

Frequency of reversal	Total loss			Electrolytic loss		
	Odd electrodes	Even electrodes	Pilot	Odd electrodes	Even electrodes	Average
	Grams	Grams	Grams	Grams	Grams	Grams
60 cycle........	0.555	0.542	0.077	0.478	+0.465	0.471
1 sec...........	0.316	0.630	0.062	0.254	0.568	0.411
10 min.........	4.019	3.844	0.110	3.909	3.734	3.822
2 weeks.........	17.356	13.487	0.111	17.245	13.370	15.307
D. C...........	17.726	0.428	0.075	17.651		17.651

Frequency of reversal	Current discharge ampere-hrs.	Coefficient of corrosion			
		Odd electrodes	Even electrodes	Average ½ current	Average total current
60 cycle	16.05	0.0154	0.0150	0.0152	0.0076
1 sec............	14.87	0.0088	0.0198	0.0143	0.0071
10 min	14.95	0.135	0.129	0.132	0.066
2 weeks.........	23.17	0.386	0.209	0.344	0.172
D. C...........	13.4	0.340			0.340

(*d*) *Outdoor Tests. Iron and Lead Electrodes in Soil.* The outdoor tests shown in Table IX are not extensive, but the cases given show reasonably good agreement with the indoor tests given above. The coefficient of corrosion at 60 cycles is slightly less than 0.01 for iron electrodes and the d-c. loss is 0.70. Considering only the d-c. tests on iron, it was noted that as the voltage necessary to maintain the current at 0.5 milli-

ampere per cm. became greater the coefficient of corrosion decreased. For example, we find a coefficient of corrosion of 0.96 for iron electrodes in sodium carbonate soil and 0.85 in normal soil on the indoor tests and only 0.70 for the outdoor tests and the potential has varied from about 10 volts on the first to 35 on the last test.

TABLE IX.

SUMMARY OF ALTERNATING-CURRENT ELECTROLYSIS TESTS—V.

Variable—Frequency of Reversal.

Outdoor Tests
Iron and Lead Electrodes
Soil and Sodium Carbonate Electrolyte.

Frequency of reversal	Total loss			Electrolytic loss		
	Odd electrodes	Even electrodes	Pilot	Odd electrodes	Even electrodes	Average
	Grams	Grams	Grams	Grams	Grams	Grams
60 cycle....	2.65	2.60	0.97	1.68	1.63	1.65 Iron
1 sec.......	9.06	7.30	5.94	3.12	1.36	2.24 Iron
D. C.......	41.96	1.73	4.61	37.35	37.35	37.35 Iron
D. C.......	871.861		6.216	865.645		865.645 Lead

Frequency of reversal	Current discharge ampere-hrs.	Coefficient of corrosion			
		Odd electrodes	Even electrodes	Average ½ current	Average total current
60 cycle.......	165.4	0.0203	0.0197	0.0192	0.0096 Iron
1 sec..........	102.	0.0589	0.0256	0.0431	0.0215 Iron
D. C..........	51.6	0.700	0.700	0.700	0.700 Iron
D. C..........	1034.	0.217	0.217	0.217	0.217 Lead

Curves

The data shown in the above tables have been plotted in curves in which the ordinates are coefficients of corrosion expressed in per cent and the abscissas are the logarithms of the number of seconds required for one complete cycle. Fig. 4 shows the data obtained with iron electrodes, this being based on the average electrode loss and the total current flowing in

any one direction through the cells. The coefficient is therefore based on the total current discharged by one electrode. It will be noted that the curve for the coefficient in natural soil is above that for soil containing sodium carbonate except the last point for direct current when the latter shows the greater loss. The values begin to rise quite rapidly at about the 10-minute cycle and reach a maximum in the d-c. test, the value for which is placed arbitrarily as far as the time is concerned. It is very interesting to note that even in the case of a cycle of two weeks duration the coefficient of corrosion is only about 0.6 and on a 2-day cycle only 0.3 of its value for direct current.

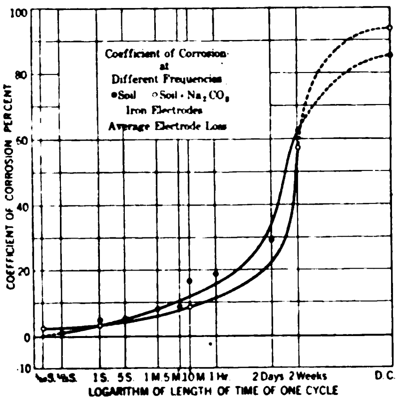


FIG 4

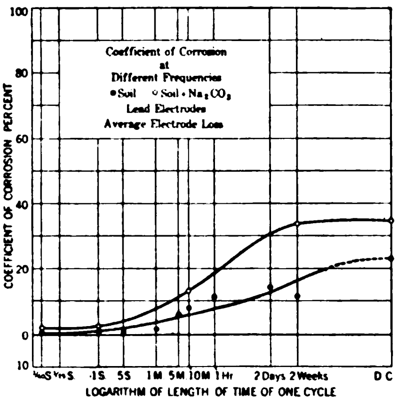


FIG. 5

Fig. 5 contains the same data on lead electrodes and here it is seen that the soil containing sodium carbonate produces a consistently higher coefficient of corrosion than the natural soil, just the reverse of the condition with iron electrodes. The tendency to rise is noticed at an earlier point or a higher frequency than with the iron, beginning with about the one-minute cycle, and at a cycle of two weeks duration the coefficient of corrosion has reached the same value as for direct current.

SUPPLEMENTARY TESTS

Since certain authors have pointed out the fact that the wave form of alternating current is affected when passing through an electrolytic cell, and since a material change in such wave form would affect the current measurements, an

oscillograph was used to determine the wave form of current passing through the cell and its relation to the potential wave impressed on it. It was found that there was no appreciable distortion of the wave shape due to the presence of the cell.

In order to determine the cycle of operation of the commutating machine exactly the current wave was observed with the oscillograph. It is seen that on the one-second cycle, Fig. 6, the current increases slightly during about the first ¼ second and falls during the remainder of the half-cycle. In the six-second cycle, Fig. 7, this rise and fall is seen and the fall continues for a considerable part of each half cycle but the waves appear to be so nearly flat top in both the 1-second cycle and the six-second cycle that no correction due to the variation between the average value and the effective value need be made.

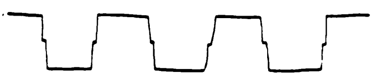


Fig. 6—Wave Shape for Slowly Reversed Current—One-Second Cycle

Fig. 7—Wave Shape for Slowly Reversed Currents—Six-Second Cycle

III. CONCLUSIONS

From the above results certain conclusions may be drawn concerning the corrosion of iron and lead electrodes under usual soil conditions when exposed to the action of periodically reversed current.

1. The corrosion of both iron and lead electrodes decreases with increasing frequency of reversal of the current.

2. The corrosion is practically negligible for both metals when the period of the cycle is not greater than about one minute.

3. With iron electrodes a limiting frequency is reached between 15 and 60 cycles per second, beyond which no appreciable corrosion occurs. No such limit was reached in the lead tests, although it may exist at a higher frequency than 60 cycles.

4. With periodically reversed currents, the addition of sodium carbonate to the soil reduces the loss in the case of iron and increases it in the case of lead.

5. The coefficient of corrosion of lead, under the soil conditions described in the report, when subjected to the action

of direct current was found to be only about 25 per cent of the theoretical value.

6. The corrosion of lead reaches practically the maximum value with a frequency of reversal lying between one day and one week.

7. The corrosion of iron does not reach a maximum value until the period of the cycle is considerably in excess of two weeks.

8. The most important conclusion to be drawn from these investigations is that in the so-called neutral zone of street railway networks where the pipes continually reverse in polarity, the damage is much less than would be expected from a consideration of the arithmetical average of the current discharged from the pipes into the earth. Where pipes are alternately positive and negative with periods not exceeding 10 or 15 minutes, the algebraic sum of the current discharged is more nearly a correct index to the total damage that will result than any other figure that can readily be obtained.

9. The reduction in corrosion due to periodically reversed currents appears to be due to the fact that the corrosive process is in a large degree reversible; so that the metal corroded during the half cycle when current is being discharged is in large measure redeposited during the succeeding half cycle when the current flows toward the metal. This redeposited metal may not be of much value mechanically, but it serves as an anode surface during the next succeeding half cycle, and thus protects the uncorroded metal beneath.

10. The extent to which the corrosive process is reversible depends upon the freedom with which the electrolyte circulates, and particularly, on the freedom of access of such substances as oxygen or carbon dioxide, which may result in secondary reactions giving rise to insoluble precipitates of the corroded metal. It is largely for this reason that the corrosion becomes greater with a longer period of the cycle since the longer the period the greater will be the effect of these secondary reactions.

Discussion on "Class Rates for Light and Power Systems or Territories" (Baum), Deer Park, Md., July 2, 1915. (See Proceedings for April, 1915 and January, 1916).

(Subject to final revision for the Transactions.)

CONTINUED FROM JANUARY PROCEEDINGS PAGE 70.

F. G. Baum (by letter): None of those who discussed the paper made any argument that my method of analysis is not correct but some question the advisability of adopting such a system. This is natural, and extreme caution should be used in adopting any plan, and no plan should be adopted that does not depend for its facts on the actual records of operation of the company in the particular territory.

Three propositions are stated in the paper, viz.:

1. That demand charges are charges to substation necessary to get the system up to frequency and voltage and ready for business, and these charges should be apportioned among various classes in proportion to the peak demands of the classes, as outlined in the paper.

2. That energy charges are only those charges that go to put kilowatt-hours into system after the system is up to frequency and voltage, that is, that energy charges are practically cost of fuel at the steam plant, or steam reserve plant, and storage water cost (not forebay storage cost) at power plant.

3. That uniform class rates, as developed in the paper, for a system or territory where similar conditions exist will be simpler, more equitable and more stable than present rates, and will tend to develop all classes of business, and tend to have commissions consider "Value of service" and to allow a constant service value for the property.

From the substation to the consumer the same method of analysis may be used. Any piece of equipment or line, etc., used jointly by two or more classes should *normally* divide the charge in proportion to the peaks. That is to get the kw. demand charge, divide by the sum of the two peaks at the time when those peaks are a maximum. Then multiply this demand by the demand of the class to get the total demand charge for the particular equipment or line for the class. If the peaks are not coincident then the demand cost is reduced because of the diversity, as is right. When we arrive at the consumers line, for transformers or meters used to supply him alone, he must bear the entire cost. Those are consumers costs.

This method then gives the relative normal cost of service to the different classes and with this method of separating demand and energy charges brings in *automatically* relative rates which will generally develop the business. This may be called the lowest measure of the value of service.

The general natural tendency of electric rates is to favor the lighting consumer, and if the improvement in lamps continues the lighting consumer will pay very little ultimately. By the proposed method it will be seen that his rate must increase

as his kilowatt-hours decrease. Unless classification of investment and expense is made and class rates made to fit the large classes I am afraid for the future of the business.

The method gives the normal relative cost of the power and will develop most business normally, but the investment charge may still be graded to different classes if the rate so determined will not give the largest net earnings for a given investment. This was pointed out in the paper.

Referring to the third principle; by this method we do not treat with individual consumers (except in special cases) but with classes. A power man may only use power during the morning or afternoon, that is for six hours corresponding to the lighting number of hours, but his rate is determined (so far as expenses up to any equipment used by him exclusively) by the class of which he is a part. In each class there should be a sliding scale which makes the rate of short time user in the class higher than that of the long time user. That is a rate scale taking into account the kilowatt-hours consumed per kw. installed.

We must not confuse the prospective electric consumer with a discussion of power factor, load factor, diversity factor, peaks, time of peaks, etc; but we should tell the consumer what he wants to know—that is, what his rate and probable consumption will be when he tells us what his installation is to be. A consumer will be satisfied generally if he knows he is paying the same rate as other consumers in the same business, that is, other consumers in the same class.

Rates should ultimately become known as applied to a certain class of business, for example the lighting class rates, the day power class, the 24-hr. class, business lighting, street lighting, etc. When the residence lighting consumer now hears of the low 24-hr. power rate he thinks he should have the same rate; but he is educated to know he must pay a rate for express freight different from that for which he ships sand in carload lots.

If my first two propositions above are accepted, it will largely result in an automatic and just finding, *from easily determined facts taken from the records of the company*, of the equitable relative rates for different classes of consumers. We determine correct relative rates by the method and do not merely say in general terms the lighting consumers shall pay *some* indefinite amount more than the other larger users, but we say *how much more* should be paid. And there is no questioning the answer if we go at the matter fairly. The third proposition will stabilize and standardize rates and remove misunderstandings. We have tried numerous methods of determining rates and no one will say they have been an unqualified success.

If managers and engineers will apply themselves to a thorough, open minded and fair study of the situation, I believe they must inevitably come to the same conclusion that I have. My study has been made from, probably, the largest general power

system, and one that has developed the diversified load to a very high state. It is therefore practical as well as analytical (and not theoretical), and the three conclusions above stated were arrived at without preconceived notions and without influence; and the conclusions are believed to be such that any one who is willing to accept a fair rate of return on a fair value will accept them. It does not agree with those who believe we should charge, *all the traffic will bear*. And besides no two men will agree on how much is, *all the traffic will bear*, which shows its fallacy. I believe electrical men prefer the certainty and stability of a fair return on a fair value, and definite methods of determining rates.

If engineers and managers can not agree among themselves as to the facts, we certainly must not be surprised if the commissions are confused. As a whole the commissions are trying to do what is right, just as are the companies as a whole. To concentrate and crystallize the varying views and methods, it is necessary that we concentrate and crystallize our ideas and facts, so that common ground may be determined to which all fair minded men must agree.

Any other course must leave the business in the uncertain state in which it has been in the past. Stability and certainty are an asset worth striving for, and the business will not be on firm ground until rates are made (1) *fair* and *liberal* as a whole to the company, (2) *equitable* as between classes of consumers and (3) *uniform* so as to make them stable, and standard for similar conditions. These results are necessary for developing the ability and eagerness desired on the part of the company and consumers.

Discussion on "Report by the Joint Committee on Inductive Interference," San Francisco, Cal., Sept. 17, 1915.

(*Subject to final revision for the Transactions.*)

Progress of the Investigation of Inductive Interference by the Joint Committee on Inductive Interference

Since the presentation of our report at the Spokane convention a year ago, the principal experimental work has been conducted at San Fernando, about twenty miles north of Los Angeles. Here the committee had completely at its disposal, for several months, a thirty-seven mile power circuit and private telephone circuit of the Pacific Light and Power Corporation, also several banks of transformers, loaned by the same corporation. These facilities, in addition to the regular equipment of instrument transformers and portable field laboratory, made it possible to conduct extensive tests along various lines. The chief points investigated will be briefly mentioned.

The unbalances to ground of a power circuit isolated from ground. This study was undertaken with reference to the residual voltage caused by such unbalances and the effectiveness of transpositions as a means of balancing the system. The conductors of the circuit used for the experiments are spaced five feet apart in a vertical plane. Tests were made under three conditions of the power circuit as regards transpositions; first, no transpositions; second, two transpositions dividing the line into three equal sections, or one barrel; and third, five transpositions dividing the line into six equal sections, or two barrels. Under each condition, tests were made consisting, in part, of residual voltage measurements with the line energized at approximately 28 kv. between wires, by a bank of transformers isolated from ground; and, in part, of measurements of capacitance and conductance unbalances to ground of pairs of conductors at frequencies ranging up to about 1000 cycles per sec. The influences of connected apparatus and of leakage under wet weather conditions were considered. As might be expected, the results of the residual voltage measurements at the fundamental frequency (50 cycles) showed no difference in the effectiveness of two over one barrel for this length of line. In the absence of a source of three-phase energy for frequencies ranging from 200 to 1200 cycles it was necessary to resort to an indirect means of determining the residual voltage at these frequencies. Measurements of the unbalances between pairs of conductors, supplemented by measurements of the total admittance to ground of different combinations of conductors, afford means of computing the residual voltage. The results of these tests at high frequencies showed a marked difference in the effectiveness of the one and two barrel systems; two barrels being, of course, better than one with the advantage increasing at the higher frequencies. It is interesting to note in this connection that the non-transposed condition of the line gave better balance at the highest fre-

quencies than at the lowest. A point was reached when the gradual decrease of the unbalance with no transpositions and the rapid increase of unbalance with a single barrel resulted in a worse unbalance for the single barrel than for no transpositions. The question naturally arises in the minds of some, as to the reason for tests at such high frequencies where the fundamental operating frequency is only 50 or 60 cycles per sec. It has been repeatedly stated and shown that the harmonics rather than the fundamental frequency components are the basic cause of disturbances in parallel telephone circuits. The practical goal of all this work is the determination of reasonable requirements of transpositions in power circuits isolated from ground as a means of obtaining effective electrostatic balance and thereby preventing harmful residual voltage.

Parallel with the experimental work, a theoretical study of the unbalances characteristic of different circuit configurations was carried out. Consideration was also given to the equivalent unbalances of a line at high frequencies.

The relationship of triple harmonic residuals to the magnetic density in grounded star connected transformers. This study included tests with both delta-star and star-star connected transformers. Since the reaction of the line is a factor in determining the residuals introduced by a given bank of transformers the investigation included tests of the influence of different line conditions.

The magnitude of triple harmonic residuals as affected by transformer connections. The comparisons were made at approximately constant magnetic density. The connections considered included star-star, delta-star, delta-interconnected-star, star-interconnected-star, and the effect of an auxiliary bank of delta-star or delta-interconnected-star transformers so connected as to act as a shunt to the line for the triple harmonic residuals introduced by the main transformers.

Induction between the power and telephone circuits. The close and uniform association of the two circuits, the two being carried on the same poles, afforded an unusual opportunity for an experimental determination of the coefficients of induction and a comparison with computed results, and for testing the effectiveness of transpositions in both the power and telephone circuits as means of reducing inductive interference.

Tests of induction at the fundamental operating frequency of the system were made by energizing the power circuit through transformers under conditions favoring in turn the predominant effect of: (*a*) balanced voltages, (*b*) balanced currents, (*c*) residual voltages, and (*d*) residual currents. The corresponding induction in the telephone circuit was measured simultaneously with the current and voltages of the power circuit. As the induction from the balanced components of voltage and current is dependent upon the transpositions in the power circuit, these tests were carried out under the three previously mentioned conditions of power circuit as regards transpositions.

The effectiveness of transpositions in the telephone circuit as a means of reducing induction arising from the several components of power circuit voltages and currents, was tested on a short section of the line which contained no power circuit transpositions.

In a short section of the " parallel," with both power and telephone circuits non-transposed, an extensive series of measurements of induction was made using many combinations of conductors and methods of energizing the power conductors. The effects of shielding were studied to a limited extent.

With a single-phase source of energy at high frequencies (Vreeland Sine Wave Oscillator) measurements were made of the coefficients of induction corresponding to harmonic residuals of high frequencies, and the effect of telephone transpositions, as a means of minimizing induction from such sources, was studied. The lack of a three-phase source of energy at high frequencies prevented the doing of any experimental work to determine the effectiveness of power circuit barrels of different lengths on the induction from the higher harmonics of balanced currents and voltages.

The computed coefficients of induction were in very close agreement with those experimentally determined. As a basis for the computations of induction from residual current it was necessary to determine experimentally the depth of the equivalent locus of earth currents. In general, the study of induction and of the effectiveness of power and telephone circuit transpositions, while not being as complete as might be desired, owing to the lack of some apparatus and the fact that only one telephone circuit was considered, has given results of considerable value.

The effect of a ground on one phase of a normally isolated system in producing abnormal residual voltages and currents was studied both experimentally and theoretically with close agreement in the results. Under the abnormal conditions of a ground on a power circuit it is, of course, the resulting residual currents and voltages which cause the greatest damage to parallel communication circuits.

Observations of the residuals of the 15 kv. network (Pacific Light and Power Corporation) which supplied the committee's temporary substation and field laboratory, were studied under two conditions of operation of the power system.

In addition to the San Fernando work there has been some work done on a study of the residuals under operating conditions at several points on grounded neutral networks. The object of these tests was to obtain information as to the magnitude of residuals to be expected under different typical conditions of operation so as to afford a basis for future recommendations as to the limitations of residuals of this type of system.

During the past year a considerable amount of work has been done on several problems by the telephone companies at the

request of the joint committee. The American Telephone and Telegraph Company has conducted extensive tests to determine the detrimental effect, on the intelligibility of conversation, of extraneous currents of different frequencies in a telephone receiver. A report of the results obtained, for single frequencies has been submitted to the committee and work is now under way with reference to the effect of multiple frequency currents of different combinations. The important bearing of this work was indicated in the discussion submitted by this committee, at the Deer Park convention, on the subject of irregular wave-forms.

Subsequent to the issuance of our report last year, the matter of the redesign of its standard telephone transposition system was undertaken by the American Telephone and Telegraph Company, in order to facilitate compliance with the committee's recommendations in regard to transpositions within the limits of parallels. The present standard system of telephone transpositions affords very limited opportunities for coordination with power circuit barrels of different lengths, to make the power and telephone circuits mutually non-inductive. For this reason, the redesign of the telephone transposition system to permit of more flexible arrangements in combination with power circuit barrels was made necessary. This modification of the telephone transposition system applies both to the standard sections and, to the short length sections. A large amount of work is involved which has not as yet been entirely completed.

At the request of the joint committee, The Pacific Telephone and Telegraph Company has submitted a report dealing with the development of balance of telephone circuits. This report is the result of an investigation of the methods and measures employed by the telephone companies to obtain good electrical balance of their circuits and to protect them against inductive interference from other telephone circuits (cross-talk) and from foreign sources. The report considers the subject from the conditions presented by the earliest experience of the telephone companies to those of the present day. This report was desired as a basis for the consideration of the subject by the committee.

The committee has recently been giving careful attention to the matter of future work. There appears to be no good reason for deviation at this time from the general program as laid down in the committee's report published last year. It is expected, therefore, that the future work will continue, as has the work during the past year, along the general lines suggested by that program. The detailed plans for the conduct of this work have, however, been the subject of much discussion. The facility with which the work at San Fernando could be carried out with both power and telephone lines completely at the disposal of the committee at all times, suggested the possibility of test lines constructed primarily for experimental purposes. Were necessary funds available, tests of great value could be of course carried out under such conditions. After carefully weighing all ques-

tions involved, it was decided that the information desired could be obtained most advantageously by a study carried out under practical conditions. In any event the committee could not, in justice to itself, properly call its work complete without actually applying in several cases the remedial measures which it proposes and noting the difficulties and limitations imposed by practical conditions.

The problem offered by any case of parallelism between power and communication circuits is capable of subdivision into two main parts. These are, first, the matters of line configuration and coordinated transposition systems to render the power and communication circuits as nearly as practicable mutually non-inductive, and second, the control of residuals and their restriction to frequencies and magnitudes which do not cause material interference either to grounded telegraph circuits or to properly transposed and balanced metallic telephone circuits. Normal operating conditions on the power system are assumed.

With reference to the first subdivision, the problem is identical for both the isolated and the grounded neutral types of power system. The second, control of residuals, differs entirely with respect to the two types of systems. For the isolated system the principle is relatively simple. Transposition of the circuit involved in the parallel, throughout its entire length, so as to obtain good electrostatic balance offers the most practical way of accomplishing the result desired. Assuming a uniform configuration throughout the line, the transpositions for this purpose must be so located that each conductor of the circuit occupies all of the conductor positions for equal distances. In other words, they must be equally "exposed" to the earth. In addition, the transpositions must be frequent enough so that their balancing effect is not rendered ineffective by the attenuation and phase changes which occur along the circuit at frequencies producing harmful interference to the communication circuits. With reference to grounded neutral systems, the control of residuals presents a more complex problem, especially on existing systems. Its solution has engaged the attention of the committees in large measure from the outset of the investigation and will undoubtedly continue to do so in the future, as this seems one of the main outstanding problems. The residuals of grounded neutral systems characteristically contain the third harmonic and its odd multiples, together with some fundamental and other harmonic components due to unbalanced load conditions. The solution of this problem, therefore, involves a very careful study of transformer connections, magnetic density, the reaction of lines upon the triple harmonics introduced by transformers, and the interaction of the different banks of grounded star-connected transformers throughout a system. The practical solution of a question of this kind requires tests of typical grounded neutral systems under actual operating conditions. Tests such as were conducted at San Fernando, under the relatively simple condi-

tions where the residuals introduced by a single bank of transformers were studied, afford, however, a good foundation for the study of the more complicated cases to be encountered in practise.

To carry out the plans just discussed, a tentative program, now under consideration, includes the investigation of one parallel involving the isolated type of power system and several parallels involving the grounded neutral type of power system. It is felt that the study of an isolated power circuit, as conducted at San Fernando, supplemented by one other investigation involving this type of power system, will afford the committee all the information necessary for it to establish, on a firm basis of scientific fact, the requirements for transpositions to give good electrostatic balance on power circuits isolated from ground, thereby preventing residuals of harmful magnitude. The complex conditions encountered on grounded neutral systems make it inadvisable that general conclusions be drawn from an investigation of a single case.

It was said above that a theoretical study has been made of the effect of power-circuit configuration on the electrostatic balance of the circuit. It is proposed also to study the effect of circuit configuration on the induction between power and communication circuits. Some work along this line has already been done, especially with reference to possible alterations in configuration of telephone phantom circuits. In general, if it is possible to make power and telephone circuits mutually non-inductive, to a satisfactory degree, by a reasonable number of transpositions installed for this purpose, it is not expected that the question of configuration for either class of circuit will become of controlling importance. Configuration of both classes of circuits will be considerably influenced by other reasons; economical methods of construction for both lines. Other things being equal, it is very desirable that circuit configurations be such that the coefficients of induction between non-transposed sections of lines shall be as small as possible.

A study of the variation with frequency of the effectiveness of transpositions in both power and telephone circuits has been suggested. Under practical conditions there are, however, many other factors, such as length of parallel, large number of telephone circuits involved and points of discontinuity within the limits of the parallel, which enter into the problem of determining the proper number of transpositions in both types of circuits. These factors are such as to enforce arbitrary and somewhat inflexible limits, so that this matter of frequency is not the determining factor in setting a limit for the number of transpositions required to obtain mutually non-inductive conditions. The effectiveness of transpositions at high frequencies was one of the chief questions proposed for experimental investigation on test lines. Such an investigation would be of undoubted scientific interest, but the practical bearing of the

subject does not seem to warrant the expense involved, especially as it is expected that the results can be obtained more economically by theoretical study.

Upon completion of the work which has just been discussed, the committee expects to draft a supplementary report to be presented to the Railroad Commission of the State of California, giving in detail the conclusions derived from its investigation from the date of its first report, and such recommendations as it feels necessary, to make the rules recommended in the former report more complete and explicit than was possible at the time the earlier report was rendered.

During the past year $7200.00 have been raised by contributions of the power and communication interests. Previous to this, $9400.00 had been raised by a similar contribution made shortly after the formation of the committee. It should be noted in this connection that this amount of money represents only a small portion of the total expended on the investigation. Both the power and communication interests have in addition to the above, contributed heavily in the time of their employees and in apparatus placed at the disposal of the committee. This has been true particularly of the telephone companies. The Railroad Commission of California has also contributed financially, and the railroads of the state have contributed through the provision of free transportation for all committee members, employees, and freight. From the outset, the investigation has had the support of communication interests with more than statewide affiliations. On the other hand, upon the power interests of California has fallen almost the entire burden of meeting the power interests' share of the expense. Of late there has been considerable discussion among the California power interests with reference to obtaining the financial support of the similar interests throughout the country. This subject is undoubtedly of far more than local importance and it is to the interest of all parties that the investigation thus begun be brought to a state of reasonable completeness. The organization and equipment of the committee and the unrivaled field for investigation offered by the conditions in California render it desirable that the work be prosecuted to a conclusion in this State. It is the hope of the Joint Committee on Inductive Interference to bring its study, which involves the mutual relationship of the two largest subdivisions of electrical industry, abreast of the present state of development in each of the two arts involved, electrical energy supply and electrical communication. Beyond this point we can not reasonably go; further progress will occur naturally with the evolution of the two arts. We believe that this result can be realized in such a manner as to leave both unfettered in their development. This, as we undoubtedly all agree, broad-minded public policy will demand.

A. J. Bowie, Jr.: I am very much interested in the effect of high frequency oscillation on telephone lines. It is a well known fact that the higher the frequency the worse would be the inductive effect upon the lines, and it is highly desirable that any effort it is possible to make should be made to keep away from the effect of high frequency, no matter what it comes from. There appeared some time ago in the *Electrotechnische Zeitschrift* some articles by Doctor W. Linke, these were in the issues of July 2nd and July 9th, 1914. He discussed transient phenomena. He had made a general study of this phenomena from many points of view with different phases, kinds of circuits, conditions and kinds of switch apparatus; and the result of this is published in the two issues referred to. In particular he discusses the effect of different types of switches, and arcs found in the different types of switches, and the voltage varia-

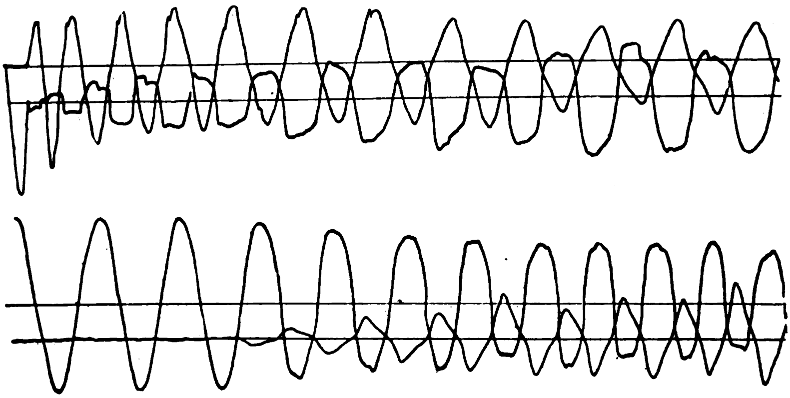


Fig. 1

tion, particularly with reference to the creation of harmonics in their own circuits. He has made tests of both oil switches, air switches without horns, and air switches with horns. His conclusions are that the oil switch causes the most serious harmonics, but the air switch without horns was gentler in its action, and that the air switch with horns was ideal in its action in suppressing the harmonic and gradually reducing the current before the point of final break.

Among others he made a test on a 10,000-kw. generator, which was short-circuited by a horn-break air switch. The generator was brought up to normal voltage before short-circuiting. The phenomenon of opening is shown by the oscillograms. The voltage curve does not show a single sharp peak or quick rise, even with the rising of the arc on the horn, and likewise with the gradual increase of resistance the voltage rises from the moment of short-circuiting slowing to the normal height, while the current changes to zero. This is shown in

Fig. 1 Fig. 2 shows the corresponding test made with the oil-break switch.

There has been a certain amount of misunderstanding of the action of arcs in air, which I think is being gradually straightened out as further experiments throw more light on the subject. At first it was supposed that the arcs which occurred in air caused destructive rises of voltages on their own circuits. It has been pretty well disclosed by many tests which have been made, among them some made by W. P. Hammond, which appeared about a year ago in the *General Electric Review*, and showed definitely that the rise of voltage which occurred from opening the horn type of switch was less than that which occurred in opening the air type of switch. Having disproven any material rise of voltage occurred on their own circuit, they were finally confronted with the fact that the arc may affect the neighboring circuit.

There are only three cases in which a rise of voltage can

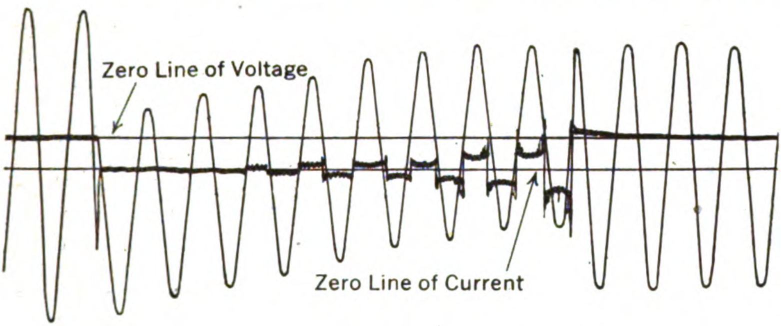


Fig. 2

occur on the power circuit which will affect the telephone circuit. The one is from a natural rise, from the opening of the switch; the second is from harmonics; and the third is from the unbalanced condition which will result from one phase opening in advance of the other phases. We cannot say definitely, either with an oil switch or an air switch, that all three phases open at the same time, in fact, it is doubtful whether they do; but no definite data have been brought forward on this subject one way or another. It is a matter which should be investigated further before any rules or regulations are passed on the subject.

John B. Fisken: There are some rules that are a little hard on the power company, possibly because they are not understood. I have been for about a year trying to find out what is meant by a "parallelism." Rule No. 1 reads that "reasonable effort shall be made to avoid new parallelisms." I think all power companies try to do that. We are told to avoid parallelisms, but are not told what a parallelism is. What I

want to know is, when a power line and a telephone line are running in a parallel direction, what is the distance between them and the length to constitute a parallelism?

On this question of air-break switches versus oil-break switches, we have in some of our lines occasion to use air-break switches. Some two or three years ago we had oscillograms taken on these lines. As I remember, the higher frequencies were not present to as great an extent with the air-break switches as they were with the oil switches. We have two lines which we have fought with for some time, and in connection with them I want to ask Mr. Babcock if the committee has made any investigation of the effect of killing the charging current on a steel tower line. My reason for asking that, is this—something like nine or ten years ago we built two lines, 60,000-volt lines, 60 cycles, that paralleled main telephone lines. We operated them many years without any trouble. What is technically known as "bats" had not put in an appearance. A few years ago the bats began to get on the scene, and it puzzled us to know where they came from, as the method of operation had not been changed in the slightest degree. We found that in taking the power off the line, there was no result, but when we came to "kill" the line, breaking the charging current, there was a result.

Now, the connection between this line and the steel tower line is this—several years ago, in order to get rid of the burning of our pole tops, we grounded the pins on both of these lines. The effect is the same on either of them. It has occurred to me since that possibly the ill effects that we get from these lines may be due to the discharge of the condensers, there are over 2000 insulators on each line, which constitute condensers, and I have thought that possibly the rush to ground through the ground wires might cause this trouble. We have solved that problem in a measure by doing our switching on the low tension side. That in many cases is not a practicable proposition. There are one or two questions which I think will have to be referred to the manufacturers, the requirements as to wave form, etc., of generators, and the transformer requirements.

J. E. Woodbridge: I can answer Mr. Fisken's question about the so-called "bats" probably by a description of the appearance of the same trouble in this territory. There have been reported to the various power companies around San Francisco some very severe bats that in some cases affected telephone operators to such an extent that it drew blood from their ears, etc. These troubles were investigated and it was found that they synchronized with the killing of certain 100,000-volt power circuits by the opening of switches. It was found that the three individual single pole oil switches, in the three phases of the 100,000-volt line did not open at exactly the same instant. They were operated by three independent air cylinders, that is, they were not mechanically connected to open

at the same instant. It was partially on account of that difficulty that the ruling was recommended to the railroad commission to provide for mechanical connection between such switches. That slight difference in the time of operation of the three phases is a small measure of what is to be found in the operation of air break switches. These air-break switches, referring now to the article by Mr. Hammond, required in some cases several seconds, that is, several hundred cycles, for the breaking of the circuit, where oil switches require, as a rule, a fraction of a cycle, and probably at the most from one to two cycles. The three arcs drawn off in air do not break simultaneously, as has been observed visually; and the breaking of one arc ahead of the other two, or two ahead of the other one, leaves full voltage supply to one of two conductors, with the other conductor or phase open-circuited. That gives the same action as the slight difference in the operation of the three oil switches just mentioned, only, presumably to a much greater degree.

J. P. Jollyman: Our study of this matter of inductive interference has pointed out to those of us who have been interested primarily from the power standpoint, one thing that is interesting and very encouraging, that the things which do the most to cause trouble with the parallel communication circuits are not essential to the operation of the power circuits. It is the little odds and ends of things that creep into the power circuits and have nothing to do with the actual business of transmitting power, that cause most of the trouble for the parallel communication circuits. With this point in view, it seems that the power company should reasonably be expected to do what it can to get rid of the things that are not essential to itself but which cause a great deal of trouble to other people.

Fortunately the desirable frequency for transmission of power represents a frequency very materially below the average frequency of voice currents. The power currents of normal frequency, which, of course, are the useful currents for the transmission of energy, where they do set up induction, set up an induction which is not as troublesome in telephone lines, at least, as the induction from the higher frequency harmonics which creep into a power system at times. With the exception of a few instances, I believe that these harmonics are of no particular importance to the power people. They do not serve any particularly useful purpose, nor are they usually of sufficient magnitude to be particularly noticeable to power people. In some cases, however, they are very noticeable to the parallel communication interests, and are a great deal more effective in causing trouble than is the primary or fundamental frequency.

The reduction of the harmonics and of their effect is, with respect to the telephone lines, at least, the principal problem before the committee at the present time; in other words, the problem is to control those frequencies in the power system,

which are not essential to the operation of the power system, but which are very disturbing to their neighbors. In the case of the telegraph lines, the lower frequencies are more troublesome than in the case of the telephone lines. Telegraph lines fortunately, are not as sensitive as the telephone lines, and the operation of parallel circuits is not so difficult. Of course, the power men know the fact, that transformer magnetizing currents do contain a certain amount of harmonics higher than the fundamental. It is possible in a new system to design the transformer connections so that the effects of these harmonics will be very largely eliminated. Some of the existing systems have many transformer connections in which the third harmonic component of the transformer magnetizing current is not taken care of within the bank itself. An important problem before the committee at the present time is to learn how to take care of this locally. It seems that this can be accomplished.

A matter of very great concern at the present time to all of the interests involved is to find out, if we can, the most practicable forms of line construction, transformer installation, etc., which will be preferable from a non-interference standpoint. A considerable option, especially on the part of the power company, exists in the form of the arrangement of conductors on a supporting structure, without any material difference of cost, or with very little difference in cost. As was pointed out in the discussion presented by Mr. Babcock, the most important problem before the committee at the present day is to find how the circuits may be built to give the least inherent mutual interference.

P. M. Downing: The report of the Inductive Committee has been criticized because it is indefinite, and does not define what constitutes a parallel or a parallelism.

As a member of that committee I do not hesitate to say that neither the power nor the telephone people were able to determine a proper definition of the term.

In view of our knowledge of the subject, neither side was disposed to make any hard fixed rule, fixing the separation between power and telephone lines. Nor are we prepared even yet to say just how great the zone of interference is under every condition of voltage, loading, configuration, etc. In other words, there are so many elements that must be taken into consideration, that a still further study of the subject must be made before a better definition can be given. The further investigations of the committee may enable them to better define the term, and it may not.

J. B. Fisken: As I understood Mr. Woodbridge in answer to my question his solution of the difficulty was that the three poles of the switch did not break at exactly the same moment. I want to assume the case that they break together as nearly as it is possible to make them break. In this particular case I would state that we have an expert switch man, who goes over our

switches all the time and adjusts them, so that as near as it is possible for any human being to make them, the three poles of the switches break at the same time. Assuming that the three poles break at the same time, then does the fact that the pins are grounded and the insulators act as condensers cause the interference when the charging current is broken.

E. E. F. Creighton: I think it is impossible to answer Mr. Fisken's question offhand, as so much depends upon conditions. The capacitance of an ordinary suspension type disk is approximately 34 micro-farads, in other words 34 times ten to the minus twelfth power. A calculation can, therefore, be made which will give the total current which would flow through the insulator to the ground. The capacitance of a string of suspension disks is equal to only a small fraction of the capacitance of the line wire between towers. I should suspect the trouble was due to the accidental arc-over on the line at the time of opening the switch, or to an unbalanced electrostatic condition of the three phases during switching.

J. E. Woodbridge: As I understand the two conditions Mr. Fisken describes, one is the condition of the neutral between the pins and the other is the resistance of the wood pole between the pins and the ground. We made some computations at one time of the amount of line capacitance which is contained in the insulators themselves, which in the case we had in mind was a string of suspension insulators. We tried to determine what proportion of the total line capacitance was made up of the capacitance between the caps and eyes of the suspension insulators, and we found that this capacitance was a very negligible part of the total, I believe a fraction of one per cent. The capacitance of pin insulators would be some comparative figure, so that I do not think that with the removal of the series resistance of the wood pole, this very small fraction of the capacitance would have any effect whatever on the coefficient of induction between the transmission line and the telephone line.

A. H. Babcock: Your attention is called to the fundamental requirements, not of any particular provision of the rules, but of the rules in general, namely; any switch, regardless of its type, its construction or methods of its operation, that causes disturbances in the communication circuits, by those very disturbances renders itself objectionable, and any such switch that does not cause such disturbances is not objectionable. If only that point of view can go home, much of the present unfortunate misunderstanding will be more easily removed.

DISCUSSION ON "A LARGE ELECTRIC HOIST" (SYKES), SAN FRANCISCO, CAL., SEPT. 17, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915).

(*Subject to final revision for the Transactions.*)

Graham Bright: One remarkable thing about the hoist described in Mr. Sykes' paper is that although it is much larger than anything heretofore built in this country, the actual performances obtained in operation are strikingly close to the guaranteed values given by the manufacturer. This shows clearly that the art of hoisting and hoist calculations are being more thoroughly understood and the performance of even the largest hoists can be foretold with certainty.

Fig. 7 in Mr. Sykes' paper shows clearly how the slip regulator cuts off the peak loads of the induction motor at the same point for each hoist.

The flywheel is large enough to supply complete equalization when hoisting from the 2000-ft. level provided the caging time is not greater than about 20 sec. Considerable saving could have been effected in the weight of the flywheel if the steel manufacturers could have supplied larger plates. The flywheel is built up of steel plates riveted together and the entire surface turned true. The greatest width that can be obtained for commercial rolled plates is 12 ft. This produces a peripheral speed of about 19,000 ft. per min. Since a steel plate wheel can be safely worked up to a peripheral speed of 24,000 ft. per min., size of the flywheel required would be inversely proportional to the square of 19,000 and 24,000 if plates 15 ft. wide could be obtained. It is true that a much more economical wheel as regards weight could be obtained by using a steel casting, but this type of wheel is not considered as safe as a plate wheel in this country.

Mining companies frequently request a flywheel large enough for complete equalization at all depths. Unless the power contract penalizes the customer for very short time peaks it does not pay to install a flywheel large enough to take care of complete equalization. A smaller flywheel will produce a variation in the power input to the a-c. motor, but since most power contracts are based on from 5 to 15 minute integrated peaks this variation will have no effect on the integrated peak. A lighter flywheel will not only cost less to install but the constant losses which occur as long as the set is in operation will also be less.

Selby Haar: I have been gathering statistics about electric hoists all over the world, and have an itemized record of about 700 electric hoists which call for a motor with a continuous rating of over 200 h.p.; of these possibly 300 are over 500 h.p., and among them is the most powerful hoist in existence. By that I mean that the most powerful hoist in the world based on its continuous output as an electric hoist.

The hoist described in this paper, as Mr. Sykes says, is the

largest electrically operated hoist in the United States, and I think it is the largest electrically operated hoist in the western hemisphere. I do not believe, that it is the most powerful hoist in the western hemisphere, because I think that record is held by an American steam hoist out inthe Rocky Mountains.

In looking over the diagrams and illustrations which are part of the paper, I note that the input to the hoist will be limited to 1850 h.p. at 4000 ft. depth. Although the hoist is designed for a 5000 ft. depth, the limiting input for 5000 ft. is not stated. That raised a question in my mind as to what that would be, because this set is provided with a motor rated 1400 h.p. Judging from my experience, the limiting input at 5000 ft. would not be any less than 1850 h.p.; and although the design of that motor is influenced greatly by the power required to start the flywheel from rest, still if the hoist be operated for any considerable time from the 5000 ft. depth, it may overload the motor, unless the slip regulator be readjusted whenever the depth of hoisting is lessened. I doubt if it will seriously overheat the motor, because the hoisting conditions in few mines can be kept steady enough to approximate a continuous overload.

Another point is brought out in Fig. 6, that is, the flywheel of this set is placed in the middle. This was the practise of the foreign builders who first developed the flywheel motor—generator set for use in hoists about the years 1900 to 1904, and was also followed, at that time by the manufacturers in this country. But about seven or eight years ago there was a change in design, and you will find that practically all flywheel motor-generator sets now being built in Europe for hoisting work are designed with the flywheel at one end of the set, and in Europe they also provide a clutch coupling of some kind between the flywheel and the motor-generator. set, so that the flywheel can be disconnected whenever desired and the motor-generator set run without the flywheel if it be so desired; and during periods of light load, say at night time and holidays when the operation is practically nominal, they do so operate the motor-generator set. That is, it is a plain motor-generator set. The load is so low anyway that the limitation of the load by the use of the flywheel is not necessary.

For the first large hoisting equipment on this principle which was installed in this country, the same design was adopted except that the coupling between the flywheel and the motor-generator set was not made so that the flywheel could be disconnected during the operation of the set. The use of this arrangement permits very substantial simplification in the mechanical design of the parts of the motor generator set.

In listening to Mr. Bright's contribution to the discussion, I note an inaccuracy of statement in that he said that this is the largest hoist built in this country. This is the largest

hoist installed in this country, but it is not the largest hoist built in this country, because the largest hoist in the world was built in this country, although it is operating in South Africa.

He also pointed out that the flywheel could have been made of larger diameter if the steel makers could have furnished larger steel plates. In this connection it should not be overlooked that the restricting feature is not always the limited facilities of the steel manufacturers, because we usually found that when we could have used large flywheels, the clearances on the railroads over which the machines would have to be shipped were such that flywheels of greater than 13 or 14 ft. diameter could not be shipped.

G. M. Eaton: I should like to ask in regard to this shipping of the flywheel, whether that refers to the shipping on ordinary flat cars only. Very much larger diameters than that are shipped on cars constructed for the purpose.

Selby Haar: The bridge and tunnel clearances of different railroads, vary enormously, of course, but a high-speed flywheel such as the one under discussion is almost invariably made in one piece. There is practically no possibility of shipping it in segments and assembling it on the site. We had special cars which were arranged to bring the bottom of the wheel very close to the ties but it usually was a physical impossibility to get more head room than the figure that I have stated. Of course, there are some railroads where larger clearances are obtained. And for this reason, an important preliminary to the design of a motor generator set is to find out how the set is going to be shipped and what the limiting diameter really is.

F. D. Newbury: There is one matter that I think is worth emphasis. It is that a relatively complicated electrical system was installed rather than the more simple and direct method of hoisting by steam. This illustrates a very important reason for the wide and rapid extension of the applications of electricity to industry. It is low in first cost and maintenance; it is possible to transmit power economically and satisfactorily; and the power may be easily and conveniently controlled. These fundamental advantages of electric drives will in many cases justify the installation of an electrical system when, apparently, the ends desired are attained in a very roundabout way.

Mr. Haar referred to the most desirable location for the flywheel. While I can see that the location of the flywheel on the end of the set might be desirable from some standpoints, there are good reasons for placing it in the center of the set; this location leaves the two ends free for the appratus that will require attention and possible repair. The electrical apparatus does need more attention, particularly on the commutating machine end, and to have it accessible is a matter of some importance. Furthermore, the location of the flywheel in the

center of the set fits in with the most economical mechanical design, inasmuch as the largest bearings are required by the flywheel, and the largest bearings are normally required in the center of the set.

Regarding the maximum possible diameter of flywheel, it is rather fruitless to discuss shipping diameters because they vary with the railway conditions in each locality, but in this particular case shipment could have been made up to 15 ft., or 14 ft. 6 in. The flywheel diameter chosen was determined by the commercial size of plate obtainable.

Girard B. Rosenblatt: Mr. Haar asked what we figured would be the input at 5000 ft. We figured it would be about 2150 h.p. The motor-generator set has capacity to take care of that much power to a greater extent than the mine will have ore at that depth. In most of the copper mines, not only in Butte but elsewhere, you cannot get all the ore from one spot, and when you are taking it out at seven tons a trip at a speed of 3000 ft. per min., it doesn't take very long to get it all away from one level. This motor-generator set, as a matter of fact, had a thermal capacity of 2250 h.p. even at the altitude at which it is installed.

Mr. Haar and Mr. Newbury mentioned the matter of the flywheel in the middle of the set. That was gone into very carefully. I believe with Mr. Haar that a majority of the modern hoisting equipments have the flywheel at the end of the set. When I say the majority, I don't mean those made by any particular manufacturer. I think, however, that most of these flywheels have considerably less weight than the wheel involved in this case. In fact I am sure of this. With flywheels of 20 tons or so, the placing of the flywheel at the end of the set is a simpler matter than with a flywheel weighing 50 tons, because flywheels of 50 tons require either a heavy bed plate, or an elaborate foundation to keep them in place. As to clutching and unclutching the flywheel, the matter of an adequate clutch coupling for a 50-ton flywheel is something to be seriously considered. It is interesting to note this was taken up for this installation with clutch manufacturers, and the matter of a clutched flywheel was abandoned. The light work in this shaft will be done with a chippy hoist, which is a small hoist with about a 300-h.p. motor, which does the running around. While the chippy hoist is at present operated with compressed air, as a matter of convenience in getting it started before the electrical apparatus was installed, it is interesting to note that the mining company has followed the suggestions of Mr. Haar and are going to put in an electrical chippy hoist.

I think Mr. Newbury brought out the fact that if plates had been available commercially for the flywheel, we could have shipped a flywheel, 14 ft. 6 in. in diameter, to this particular place.

M. H. Gerry: The hoist problem in Butte has been an interesting one, and one which I personally have known of for many years. They installed at that point a very large air installation, following the original very large steam installations, and many of us who were closely associated with the interests in that section took issue with the advocates of air hoisting. The installation of this equipment has demonstrated that the application of electricity to mine hoisting is correct as against the indirect application by the use of compressed air, furnished by compressors driven by electric motors. The efficiency is much higher, and as time goes on it will be better than the present figures, because there are so many losses that increase with time when air is used.

In reference to the flywheel diameter, I think the general tendency in the future, will be to lighten the flywheels and take a little more variation on the sets. That, of course, is a local problem, and every installation will have to take care of itself.

Girard B. Rosenblatt: Mr. Gerry alluded to the comparative efficiency of the air system compared with the direct electrification of the hoist. We have no actual costs on the air system; but taking, the manufacturer's statement as to what losses were obtained with the electric system, and they were substantiated as reasonably correct by test, and taking the manufacturer's claims with respect to the air system, I might say that the best efficiency that was shown by any air hoist in Butte was 32 per cent from the electric line to the calculated theoretical work done in lifting so many tons of material at such and such a speed through so many feet of shaft. On the same basis this electric hoist has developed something like 46 per cent efficiency. So we have a very direct comparison between the efficiency of the two systems. But when the direct electrification of hoisting was considered in Butte, efficiency was relegated to about third place. What the people wanted first of all was absolute reliability. They wanted to be sure they could get the ore out at all times, no matter what happened. Next they insisted on absolute safety. Third, they were after economy. It took a long while to convince the people who owned the mines that direct electrification was what they ought to have. An installation of a large electric hoist like this was something that no one connected with that mine had ever seen, while the air hoists closely resembled steam hoists with which they were thoroughly familiar. But I think the electric hoist has convinced every one of its superiority.

W. M. Hoen (communicated after adjournment): The installation described represents a distinct advance in electric hoisting equipment. Although hoists of this type are very infrequent on this continent, installations have been more numerous during the past few years. The equipment represents a marked advance in the design of the various machines, but more especially in the control and auxiliary equipment. The direct-

connected unit eliminates gears and gives an efficient and quiet running hoist.

The control apparatus is of the magnetic type and consists of a group of contactors which are operated by a master switch installed on the hoist. This type permits the main control to be designed without limitation as to weight and space, and reduces the controller maintenance to a minimum. The only current handled by the master controller is that required to actuate the contactor solenoids and consequently is very small. Safety features, consisting of over-travel and a limit to the acceleration and retardation can be very easily applied. This type of control removes from the presence of the hoist operator all switches which have a tendency to flash.

By means of additional contactors and a simple latch on the hoistman's lever, increased rope speed is permissible for short intervals by weakening the motor field. This mechanical latch is so arranged that it is necessary for the hoist to attain normal rope speed before the additional speed can be utilized.

DISCUSSION ON "THE MODERN ELECTRIC MINE LOCOMOTIVE," (BRIGHT), SAN FRANCISCO, CAL., SEPT. 17, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915).

(Subject to final revision for the Transactions.)

Wilfred Sykes: The increasing size of mine locomotives and consequently the increased power of the individual units makes it necessary, if a reasonable design is to be made, to find some way of removing the heat from the motor. The use of blowers is a very simple method and is found on all locomotive designs for main line electrification. That increased capacity can be obtained in this way is of course well known, however, this arrangement cannot be used on all types of mine motors. If the motor is not so designed that the air can come in contact with the parts where the heat is generated, the blowing of air through the machine will not very greatly increase the continuous capacity. This has been shown very clearly in attempts that have been made to increase the continuous capacity of large mill motors for ore bridge service. Unless the armature core is provided with ventilating ducts in a similar way to open machines, the forcing of air through the frame makes only a comparatively small difference. In one case which I tested, the continuous capacity was increased only about 15 per cent. This motor had a solid core and forced ventilation had not been anticipated when the machine was designed.

There is of course a limit to the increased capacity that can be obtained by forced ventilation. It has been found that when the velocity of the air over the surface to be cooled exceeds about 2000 ft. per min. the amount of heat carried away is not materially increased. Apparently this figure represents the best speed for air circulation.

M. H. Gerry: There is every reason to believe that properly designed motors can be very materially reduced in size and weight by proper forced ventilation. A mine locomotive is primarily a machine where space is of great importance.

E. H. Martindale: I would like to ask Mr. Eaton what the tendency is in present practise towards undercutting the mica on mine locomotives. In the electric railway field, probably 90 to 95 per cent of the motors of this country are slotted, and some of the mining companies are now slotting their commutators. Where they can keep oil from the commutators and occasionally blow out the motors to remove the coal dust. I believe slotting has been very successful, but any oil on the commutators with coal dust present is sure to cause short circuits if the equipment is neglected.

G. M. Eaton: Mr. Martindale has asked a question in regard to the undercutting of the mica. That practise was followed quite a number of years ago, but has been quite generally abandoned on mine locomotive motors. When it was first suggested to install fans on mine locomotives, the company

which I represent was opposed to the plan, believing that a little fan motor was a complication that it was not wise to put into the hands of the ordinary operator of a mine locomotive. It was thought that the main motor being designed on the basis of the ventilation, would be overloaded shortly, when the fan motor had failed through lack of attention. However it was found in this installation that the men take to it greatly. There is a feeling of pride on the part of the men that their locomotive is the best in the mine.

W. M. Hoen (communicated after adjournment): As the development of a large coal mine progresses, large tonnages must be hauled over very great distances. The track gage and clearances limit the size of the engine and the motors which may be supplied. In short-distance haulage the maximum loads determine the weight of the engine and if the motor capacity is sufficient to take care of the maximum possible overload, the equipment will take care of average mining conditions. However, when the haul becomes very long the continuous or all-day capacity of the equipment becomes the limiting feature. The continuous capacity of a standard mine motor generally averages between 40 and 50 per cent —at a reduced voltage—of its hour rating. In order to haul the required tonnage without excessive temperatures on the motor it sometimes becomes necessary to utilize additional locomotives so as to permit of an increased layover; otherwise, the high motor temperatures will result in armature burnouts with high maintenance charges.

The addition of a blower giving forced ventilation simply increases the radiating capacity of the motors by carrying off the heat and giving much lower temperatures for the same service. While it is true that the addition of a blower and conduit slightly increases the complications in locomotive construction, the increased capacity obtained from the motors greatly over balances the disadvantages. The writer believes that this method should only be used on the larger engines such as are used for main line haulage. The increased advantages obtained are much greater in proportion to the motor capacity than would obtain in the smaller units. On the smaller type engines the increased capacity can generally be obtained by using the next available size of motor equipment which method is generally not available in the case of the larger locomotive. This method is really an adoption of that which is now universally used in modern railway equipment, except that due to the narrow gages prevailing in mine practise it is necessary to use a separate motor-driven blower.

Discussion on "Harmonics in Transformer Magnetizing Currents," (Peters) San Francisco, Cal., Sept. 17, 1915. (See Proceedings for August, 1915.)

(Subject to final revision for the Transactions.)

D. I. Cone: In the paper by Mr. Peters there is discussed the case of a bank of receiving transformers supplied over a line energized by another bank. It is stated that if the line sides of the banks are connected in star and their neutrals grounded, a path is furnished for third harmonic currents, in phase in the three line-wires.

It is desirable to further examine the conditions governing the third harmonic current in the lines; especially since in Fig. 6 of the paper, there is inconsistency among the arrows purporting to represent it.

Consider first the case where both banks are connected star-star with neutrals isolated. The fundamental induced e.m.f. in each transformer of the receiving bank, is, neglecting the effect of the line, practically equal and opposite to the induced e.m.f. in the corresponding transformer of the supply bank. Therefore, if the transformers are similar in character, the induced third harmonic e.m.fs. in the two banks will also be practically equal and opposite in phase. Hence grounding the line-side neutrals will not cause a third harmonic current to circulate through the two banks, the wires in parallel and the earth, since there is no resultant, e.m.f. to cause such a current. This fact can be otherwise pictured as follows:

Grounding the line-side neutral of the supply bank causes the voltages from line-wires to ground to be distorted in such manner that no third harmonic magnetizing current is required in the receiving transformers in order to induce the necessary counter e.m.f.

Evidently, in practise, where there are differences in characteristics among the several transformers, and where the fundamental induced voltages in corresponding phases of the two banks are only approximately opposite in phase, there will be resultant third harmonic e.m.fs. causing circulating neutral currents. This effect is, however, a differential, rather than a cumulative one.

The result is, that the lines are maintained at a third harmonic potential difference from ground. If the length of line is such that the admittance from the three wires in parallel to ground is considerable, there will be an appreciable neutral current, the two transformer banks operating as third harmonic generators in parallel. The same reasoning holds for the case where the station-side windings of both transformer banks are connected in delta. In this case the presence of third harmonic circulating currents in the deltas in general, greatly lessens the third harmonic voltage on the line-wires.

Another case which occurs is where the supply bank is connected star-star, and the receiving bank star-delta. In this

case, grounding the line-side neutrals affords a path for the third harmonic magnetizing current of the star-star bank through the line-wires, the line side of the star-delta bank and the earth, for the star-delta bank is short-circuited to currents in phase in the three line-wires. The case is the same if supply and receiving banks are interchanged. It is shown in Fig. 10 of the paper.

The effectiveness of the third harmonic current in reducing the third harmonic induced voltage depends on its phase. If the third harmonic current is leading, it tends to accentuate the third harmonic voltage rather than to decrease it. This reaction is discussed in some detail in the PROC. A. I. E. E., May, 1914, by Mr. Blume.

It seems worth while in this connection to plead for a careful distinction in usage between the exciting current and its components, the magnetizing current and the energy current, in quadrature and in phase, respectively, with the impressed voltage.

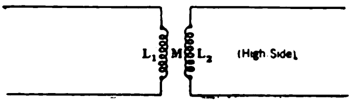


FIG. 1 (VOLTAGE RATIO 1:K)

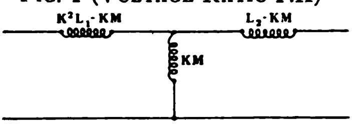


FIG. 2

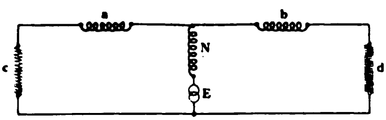


FIG. 3

H. S. Osborne (by letter): A determination of the distribution in three-phase systems of the third harmonic components in the magnetizing currents of transformers or of other harmonic components of the magnetizing currents, is facilitated by the method of analytical treatment given below.

It is customary for convenience in computations to represent transformers by *H* networks representing the equivalent one-to-one transformers. This is illustrated in Figs. 1 and 2, in which the transformer of Fig. 1 having a voltage ratio of *K* to 1, is represented by the network of Fig. 2, where the impedances are all referred to the high-voltage side of the transformer. The series branches of the *H* are merely the primary and secondary leakage impedance, and the bridge is the mutual inductance, or more accurately, the mutual impedance.

The behavior of any harmonic component of the magnetizing current can be computed by assuming the component to arise from the occurrence of a generator in series with the bridge impedance, as shown in Fig. 3. The voltage *E* of the fictitious generator is the component of this frequency in the terminal voltage of the transformer when the corresponding component of the magnetizing current is totally suppressed. The mutual impedance *N* for the component under consideration is the ratio of voltage *E* to the current *I* of the same frequency which would flow in the magnetizing current if it had no external impedance to overcome.

With any external primary and secondary impedances c and d the current flow of the particular component and the corresponding primary and secondary terminal voltages are approximately as follows:

$$i_1 = I \frac{y_1}{y} \tag{1}$$

$$i_2 = I \frac{y_2}{y} \tag{2}$$

$$v_1 = E \frac{y_n}{y} \frac{c}{c + a} \tag{3}$$

$$v_2 = E \frac{y_n}{y} \frac{d}{d + b} \tag{4}$$

Where a and b are primary and secondary leakage impedances.

$$y_n = \frac{1}{N}$$

$$y_1 = \frac{1}{a + c}$$

$$y_2 = \frac{1}{b + d}$$

$$y = y_1 + y_2 + y_n$$

These equations are of particular interest applied to the third harmonic component of the magnetizing current of three-phase banks of transformers. The equations apply to one transformer of the bank. The different usual connections give the following special equations.

(1) Delta-Delta.

In this case c and d are both zero, and I divides between the primary and secondary inversely as a and b, the leakage impedances.

(2) Delta-Star.

In this case $c = 0$

The voltage on the star side on open circuit (per transformer) is approximately

$$E_2 = E \frac{a}{N} \tag{5}$$

and this regulates through the impedance of approximately

$$z = a + b \tag{6}$$

(3) Star-Star
Equations (**1**) to (**4**) apply.

If the primary side is non-grounded, c becomes nearly infinite and the open circuit voltage on the other side is

$$E_2 = E \tag{7}$$

and the voltage regulates through an impedance

$$z = N + b = N \text{ approx.} \tag{8}$$

The use of these equations can perhaps best be illustrated by an example.

In the case of grounded star windings, impedances c and d are impedances per wire between the power line and ground, and for transposed lines are three times the impedance between the three wires of the circuit in parallel and the ground. The approximate magnitudes of this impedance for a typical high-tension line, open circuited at the distant end, is given in the following table for distances which are different fractions of a wave length. The impedances are computed for 180 cycles assuming 4/0 line conductors. For other sizes of wire or for other frequencies the magnitudes would vary somewhat, but the general range and particularly the variation in angle is typical for the given fractions of wave lengths.

TABLE I.

Fraction of wave length in sixteenths	Length, Miles			Impedances per wire
	(3rd) 180 cycles	(9th) 540 cycles	(15th) 900 cycles	
1	53	18	11	$60 - j\,2{,}400$
2	105	35	21	$40 - j\,1{,}000$
3	158	53	32	$35 - j\,400$
4	210	70	42	$40 - j\,0$
5	263	88	53	$55 + j\,400$
6	315	105	63	$150 + j\,1{,}000$
7	368	123	74	$440 + j\,2{,}300$
8	420	140	84	$13{,}300 + j\,0$

For lengths less than a sixteenth of a wave length the impedance is largely determined by the capacity between line wires and ground, and is roughly inversely proportional to the length of the line.

To illustrate the use of the equations, computations have been made for the third harmonic in the case of two 60-cycle transformers, using the following assumptions:

E (third harmonic) = 0.7 rated terminal voltage.

I (third harmonic) = 0.01 full load current.

Leakage reactance = 3 per cent in each winding (6 per cent total) for fundamental, and three times that for third harmonic.

Effective resistance of mutual impedance (N) equals 5 per cent of total impedance, and effective resistance of leakage impedances (a and b) is 10 per cent of total impedance.

The numerical results obtained by the use of these assumptions and of the values of line impedance given in Table I are tabulated in Table II, in which all figures refer to the high-tension side of the transformers.

TABLE II.

Voltage of transformer	33,000	6,600
Kw. capacity	200	300
Full load current	6 amperes	45 amperes
E	23,000 volts	4,600 volts
I	0.06 amperes	0.45 amperes
N	20,000 + j 400,000 ohms	500 + j10,000 ohms
$a = b =$	50 + j 500 ohms	13 ohms 1.3 + j 13
Delta-grounded star		
E_3	30	6.
z	100 + j1,000	2.6 + j26
Length of line to resonate	105 miles	about 200 miles
At resonance i_3	0.2 amperes	0.15 amperes
v_3	200 volts	4 volts
Star-grounded star		
E_3	23,000	4,600
z	20,000 + j 400,000	500 + j10,000
Length of line to resonate	0.3 miles	About 15 miles
At resonance i_3	1 ampere	9 amperes
v_3	400,000 volts	90,000 volts.

These results apply to but one transformer of the three-phase bank. It should be noted that the total current in the ground, is three times the third harmonic current given above.

In these cases it is to be noted that with the delta-grounded star connection the third harmonic voltages produced by resonance effects are not dangerous to the power systems, but a considerable fraction of an ampere of third harmonic current may be caused to flow in the ground, and this is enough in some cases to cause disturbances in nearby telephone circuits. These results accord with general experience, and it is supposed that the author did not have telephone induction in mind when writing the statement that the third harmonic current under these conditions is "generally so small that it is of no consequence."

In the cases of star-star connection it has for convenience been assumed that only one winding was grounded. The same

results can of course be obtained with both windings grounded, taking account of the line connected to both line windings, and reducing the whole to equivalent impedance referred to the high-tension side. The figures indicate that under the conditions assumed, dangerous resonance voltages could be produced with certain lengths of line, particularly with large transformers and moderate voltages. With very high voltages and small capacity transformers there would be relatively little likelihood of dangerous resonance effects with the third harmonic when the high-tension side of the transformer was connected to a line of reasonable length. Of course resonance effects might be obtained by the combined action of lines connected to the primary and the secondary, one having a positive and the other a negative reactance.

The author speaks of a line with grounded star transformers at each end. Under these conditions the third harmonic e.m.fs. in the two banks of transformers will frequently tend to oppose each other. If they were equal in magnitude and opposite in phase, no third harmonic current would flow at a point in the line midway between the transformer banks, and the distribution of third harmonic from each transformer bank would be the same as though the line were open at the middle.

L. P. Ferris: In the paper by Mr. Peters, in discussing the effect of the third-harmonic delta-circulating current of a delta-star bank of transformers, it is stated that this results in the cancellation of "all the third-harmonic voltages except that due to the reactance of the transformers." It would be more accurate to include also the resistance component, as well as the leakage reactance of the windings. This omission is doubtless made because the resistance is generally very small in comparison with the reactance. The author goes on to state that the voltage corresponding to this reactance drop in the delta "is generally so small as to be of no consequence." From the standpoint of inductive interference it is perhaps stating it too strongly to say that this voltage is of no consequence in cases of parallelism between power and telephone circuits for considerable distances.

Regarding inequalities in the units forming a bank of delta-star connected transformers the statement is made that the circulating current is the same in all three units. One is led to infer from this that there can be no third-harmonic flow between any of the units and the line on the delta side. This case appears somewhat analagous to the open-delta case considered later on in the paper. In the latter case there is, of course, a third-harmonic current in two of the line conductors. In the case of the closed delta with inequalities among the several units there would be an adjustment of magnetizing current among the three units which would require a small flow of third-harmonic into the line conductors to compensate in part for the inequalities. As compared with the open-delta

case, this third-harmonic current would, of course, be very small.

The author discusses the condition where the neutral on the high-tension side of a bank of star-star connected receiving transformers is grounded and the secondary neutral of the step-up bank isolated. For this case the paper states that the third harmonic stresses will appear between the coils and ground. (These stresses will be graded, increasing to a maximum for the coils adjacent to the line terminals.) The statement is then made that "since the neutral point is pulsating or rotating around the zero point, it is obvious that the whole system is made to pulsate, below and above ground, an amount equal to third harmonic voltage in the phases." The "zero point" referred to by the author is not specifically defined. The most natural point of reference, and one most generally used in discussing such problems, is the earth. If the earth is, in this case, taken as the zero point it should be obvious that the neutral point of the receiving bank of transformers, which I assume is the bank referred to in the discussion, remains at all times at the potential of the earth or zero point of reference. It is for this reason that the whole system is made to pulsate at third harmonic voltage. Were this neutral point itself to pulsate, which it would do if isolated from ground, the whole system would not pulsate at third-harmonic voltage but would remain at practically ground potential in so far as the third-harmonic was concerned. In this case the third-harmonic stresses increase to a maximum at the neutral point. This is quite easily pictured, for with the neutral isolated we have as the external circuit for the third harmonic, the capacitance to ground of the three line conductors in parallel, in series with the capacitance of the neutral point to ground. For any operating system there is little doubt that practically the entire third harmonic voltage will appear between the netural point and ground with an inappreciable amount between line conductors and ground. I have seen this amply demonstrated by tests, were experimental evidence needed to confirm this conclusion.

A small tertiary delta is recommended for star-star connected transformers to eliminate the third-harmonic voltages. Undoubtedly such a winding will greatly reduce the third harmonic voltages but one must take exception to the use of the word "eliminated." The degree of elimination will depend upon the impedance of this tertiary delta.

With reference to the circulation of third-harmonic current between grounded star-star and star-delta transformer banks, it is stated that this will be sufficient to "eliminate" the third-harmonic voltages and thereby "eliminate" the corresponding electrostatic induction in neighboring lines. I must again take exception to the use of the word "eliminate." The third harmonic voltage may under such conditions cause interference, particularly if a parallel occurs near the star-star end of the

line. It should be noted also that this condition favors maximum electromagnetic induction. With both banks in star-star, as pointed out by Mr. Cone, the third harmonic e.m.fs. are in series opposing (not strictly so if the connecting line is long.) This condition favors maximum electrostatic induction together with some electromagnetic induction if the line connecting the two banks of transformers is of any considerable length. Connecting the two banks in delta-star gives the minimum electrostatic and electromagnetic effects. In this reference only straight delta-star or star-star connections are considered.

In general, it should be noted that whereas for the purposes of Mr. Peters' paper it is perhaps unnecessary to take into account the reaction of the lines upon the third harmonic currents and voltage it is very important to consider the line reactions in any study concerned with the inductive interference caused by triple harmonics in grounded neutral systems.

N. S. Diamant (by letter): Mr. Peters does not make clear the fact that starting with a sine wave of flux, the induced voltage will be sinusoidal, but not so with the impressed voltage unless the resistance drop is negligible compared to the reactive drop.

He seems to attribute the distortion of the exciting current to the variable permeability but soon he introduces the hysteresis loop and the well known graphical methods. Now starting with a sinusoidal flux and assuming the resistance drop to be negligible, the distortion of the current will be found to be due fundamentally and primarily to the saturation curve and it is easy to see that in this case when the fundamental current wave is zero, *i.e.*

$$i_{fund} = 0$$
$$e = \text{maximum and}$$
$$\phi = 0$$

and consequently when the flux wave passes through zero all the higher harmonics of currents, i_h, will add up to zero. If there is only the third harmonic, then it will be in phase with the fundamental. What the hysteresis does mainly, is, that it necessarily shifts the above described phase relationship so that i_{fund} has a component in phase with the e.m.f. sufficient to supply the hysteresis loss.

The well known graphical method shown in Fig. 2 of the paper will give a current wave consisting of harmonics and a fundamental which can be split into two components i_{af}, the active and i_{rf}, the reactive or magnetizing component. The effect of the eddy current losses is, of course, to increase the active component. To summarize, then, the distortion is due primarily to variable μ, and for the saturation curve or extremely thin hysteresis loops when $i_{fund} = 0$, $i_h = 0$. But in the case of the hysteresis loop not only μ is variable but it has different

values for given ascending or descending values of the flux and the above relation does not hold. Finally it would be possible to have variable μ and sine wave of flux and current, provided the hysteresis loop is ellipsoidal or approaches the shape of an ellipse closely.

It may be well in this connection to look at the question from a broader point of view, and mention that variable resistivity or permittivity (dielectric constant) will produce wave distortions.

J. F. Peters: The inconsistency in Fig. 6 referred to by Mr. Cone is that the arrows indicating the flow of current through the ground connection of the step-down bank of transformers should point up from the ground; this reversal of arrows is very evident from the directions indicated by the other arrows of the figure.

The zero point for the star-star to star-star operation with the neutral of the step-down bank grounded, referred to by Mr. Ferris, is the earth. The neutral point of the fundamental voltage under these conditions rotates around the zero point as stated in the paper and indicated in Fig. 9.

DISCUSSION ON "PHENOMENA ACCOMPANYING TRANSMISSION WITH SOME TYPES OF STAR TRANSFORMER CONNECTIONS" (ROBINSON), SAN FRANCISCO, CAL., SEPT. 17, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915.)

(Subject to final revision for the Transactions.)

Harris J. Ryan: In cases I and II: The author says that the abnormal condition "is explainable by a periodically reversing leg," yet there is nothing in the paper nor in common knowledge to enable one to understand just what this "leg" is and what cause made it reverse. The author does not state for case III whether the abnormal condition was temporary or stable, a matter obviously of great importance. In explanation of the formation of the in-phase double frequency e. m. fs. applied between line and ground having effective values of four times the line voltage, "two sine wave e. m. fs. of normal frequency" are assumed to interact to form their product and thus to develop a double frequency resultant. Yet it is fixed knowledge that e. m. fs. interact to add or subtract and never to form a product-resultant. Double frequencies are produced only by products and never by additions or subtractions. Matters of this sort are not in accord with the statement in the abstract of the paper that the "data are omitted from the text to a large extent because the details could not add materially to the discussion." The abnormal formation of large in-phase double frequency e. m. fs. applied from line to ground in a recognized system of transformer connections is a matter of importance. Conclusion VI should not go unchallenged for the reason that no demonstration in this paper appears to be of such a character as to lead "to the comprehensive understanding of the possibilities and impossibilities" therein referred to.

H. Stephenson: Several years ago, I made some tests to determine the effect of the even harmonics. Ordinarily we say in transformer connections we can have only odd harmonics present; but it is possible under certain conditions to have even harmonics, and they may have injurious effects.

Two transformers were connected, one side in multiple, the other side in series; the current being forced through the windings, thereby magnetizing the core in one direction. Then we applied alternating excitations to the other side, so we are superposing an a-c. excitation on a d-c. excitation. The resultant magnetizing or exciting current contained quite a pronounced even harmonic, depending upon the amount of d-c. excitation applied. The resultant waves obtained by oscillograms were unsymmetrical. The even harmonic has the effect of overcoming the d-c. magnetization. This condition, of course, is not ordinarily met with but it is encountered in three wire synchronous converters, provided the halves of the transformer are not divided so that the return direct current does not flow through the halves of the windings in opposite directions. It is also encountered in certain cases of art furnace work, the art furnace having the property of rectifying current to a certain extent.

W. A. Hillebrand: It is my belief that the essential phenomena described by Mr. Robinson are due to those very phenomena of magnetic saturation that have just been touched upon. A further reason for that belief is this: Those even harmonic currents represent a certain amount of power represented by the I^2, of the line if nothing else. Assuming that there is no even harmonic in the generator wave, it is impossible I think to obtain that power except by the interposition possibly of a saturated iron core. This phenomenon of the production of an even harmonic by the superposition of a current wave on a partially saturated iron core is, I think, rather common.

J. P. Jollyman: Certain of the conclusions reached by Mr. Robinson are so briefly stated that I think they are likely to be slightly misleading. The second conclusion is:

" The use of grounded neutral star-connected auto-transformers in long distance transmission is also a dangerous practise unless a tertiary delta, or its equivalent, is used."

I think Mr. Robinson means that this might be a dangerous practise on a system operating with an isolated neutral at the generating plant. I know of banks of transformers employing this connection which have been in successful operation for some time, transforming large amounts of power from the higher voltage to the lower voltage, and occasionally in the reverse direction.

Mr. Robinson's fourth conclusion is: " The use of star-star transformers, or auto-transformers on a grounded neutral transmission system is safe if tertiary deltas, or their equivalents, are used at enough points to stabilize the neutral. With this type system, a liberal factor of safety is necessary in order to cover the emergency of the failure of the transformers containing the tertiary deltas."

If the transmission system is a grounded neutral system, the neutral is stable inherently. The step-up connections feeding that system must keep it stable, or it is not a grounded neutral system. It is entirely feasible to operate a star-star system with no deltas in it whatever. I know of large systems which have been and are occasionally operating star-star with no delta connections whatever.

The fifth conclusion is: " The instability of the neutral due to double frequency e. m. fs is the reason why the grounded star transmission without secondary or tertiary deltas or their equivalents, is condemned as bad practise."

I think my last remarks apply to this conclusion, that if your system is star-star straight through, and the neutrals are grounded on your generators and on your transformers, both on the low tension and high tension side, the system is inherently stable, and does not necessarily need any delta connections in it whatever.

I think Mr. Robinson's remarks apply particularly to the case where you are feeding from an isolated system into a star-star bank of transformers with the neutral on the feed—in side

grounded. That is unstable, and the grounding of one of the high tension line wires put an abnormal voltage on two of the transformers involved in the connection.

I particularly wanted to call attention to the fact that auto-transformers used on a grounded neutral system under the proper conditions are perfectly stable and perfectly feasible.

F. F. Brand: Regarding Mr. Robinson's paper it would be of great benefit to us if he would give us a little more data concerning the even harmonics which are under discussion in his paper, particularly stating whether they were under transient or stable conditions of operation. I do not recollect that the presence of even harmonics has been noticed in any system, unless as mentioned by Mr. Stephenson, they were produced by direct currents superposed on the system or by synchronous converters operating on a three-wire d-c. system under unbalanced load. I do not quite see how it is possible to get even harmonics under conditions produced by a saturated core unless the alternators connected to the system have a pronounced even harmonic which is very unusual in alternators and furthermore I do not see how it is possible to get a core saturated in one direction under stable conditions except by d-c. excitation on the core.

One other point I would like to mention which has been brought up in the various papers presented and that is regarding the use of separate delta winding or what has been known as a tertiary winding to eliminate triple frequency harmonics. It has been commonly thought that this extra delta winding had to be only sufficiently large to take care of the triple frequency component of the magnetizing current of the transformer under ordinary conditions. This is not the case. It has to take care of the higher triple frequency currents which circulate in transient conditions such as switching, etc., when the transformer core is frequently magnetized to a very high value. Furthermore in any transformers in which a triple frequency voltage exists between line and neutral which are connected on a grounded system it is necessary that this tertiary winding take care of the total triple frequency charging current of the whole system. This is usually so large that this tertiary winding must be made very large and it is my experience that it is only safe to make this winding of an equivalent copper section to other windings.

This brings out the fact that the only really economical and perhaps safe transformer for *YY* connection is three-phase core type in which these triple frequency voltages in any large degree cannot exist between line and neutral.

L. N. Robinson: Referring to the discussion by the first speaker, I would say that the term " leg " is used in perhaps the popular sense, meaning a limb or branch of a star or Y connection; *e.g.* the leg voltage of a Y-connected bank of transformers is the voltage measured between line terminal and neutral.

In Case III, which gave the large second harmonic voltages, the phenomenon was temporary at the lowest values of impressed

voltage for which it obtained; but at higher values of impressed voltage, the vibrations became more violent and the second harmonic was a stable phenomenon, remaining constant throughout runs as long as one-half hour.

Professor Ryan's statement concerning " 'two sine wave e. m. fs. of normal frequency ' assumed to interact to form their product and thus develop a double frequency resultant " is not quite clear. However, the paper does assume, and I believe it will be borne out by further investigation, that the double frequency resultant is the physical product of two single-frequency e. m. fs. It is obviously not the mathematical product because the double frequency resultant is only about four times one of the single-frequency factors.

Mr. Stephenson has brought up the subject of the production of even harmonics in transformers by excitation with a combination of alternating and direct currents, which was treated by J. B. Taylor in a paper published in the TRANSACTIONS of 1909, pp. 725-732. The possibility that the even harmonics, found in the observations under discussion, were due to direct current excitation or residual magnetism was thoroughly examined and discarded because the even harmonics were so enormous, were not present at small values of impressed voltage and occurred similarly in two banks of transformers of different ratings and manufactured by different factories.

Mr. Jollyman has called attention to the statement that it is necessary to employ a tertiary delta or its equivalent in order to stabilize the neutral of a star-star connected transformer bank in which only the line side neutral is grounded. The terms " tertiary delta " and " its equivalent " are sufficiently defined in Rule II-g (2) of the Report of the Joint Committee on Inductive Interference published in the PROCEEDINGS of September 1914. There are several means of obtaining an equivalent tertiary delta; for example, a Y-connected generator, supplying a Y-Y-connected bank of transformers, will serve as an equivalent delta for that bank if the neutral of the generator is connected to the primary neutral of the transformer bank.

As to conclusion IV, cases are known to have existed in which grounded neutral auto-transformer banks connected star without tertiary windings have given very unsatisfactory service when feeding from a grounded neutral system into an otherwise isolated neutral system. One such case in point, is a bank of auto-transformers without tertiary windings, which steps up at the receiving end of a 125-mile line, the generator end of which is connected to several banks of star-delta connected transformers with grounded neutral on the line side.

Mr. Brand and others have mentioned a desire for further data. The observations, as stated in the paper, extended over several months, and make voluminous report, all of which it does not seem desirable to present here. However, arrangements have been made to append a few typical wave shapes to the paper, when it is reprinted in the TRANSACTIONS.

The author has endeavored to explain the phenomena, but does not feel that sufficient work has been done to warrant a final conclusion. The object of the paper was to present the idea in the hope that discussion and corroboration would develop the physical and mathematical conceptions into such form that they might be more readily applied.

To be presented at the 320th meeting of the American Institute of Electrical Engineers, New York, April 14, 1916.

(*Subject to final revision for the Transactions.*)

HIGH-VOLTAGE D-C. RAILWAY PRACTISE

BY CLARENCE RENSHAW

ABSTRACT OF PAPER

During the past 10 years, the operation of electric railways at d-c. voltages of 1200 and 1500 has become common and higher voltages have been shown to be practicable. The paper deals first with the fundamental differences in apparatus for 1200 or 1500 volts as compared with the former 600-volt standards and indicates the apparent tendency of general practise with regard to a number of alternative constructions which must usually be considered in each specific application of these systems.

Referring then to the use of higher d-c. voltages which is just beginning, it points out the tendency to reach an ultimate maximum by employing a multiplicity of voltages differing but slightly from each other, such as 2400, 3000, 3600, 4200, etc, for successive installations. It recommends, in order to avoid the confusion which must surely result from this, that efforts be made to establish at once a single standard for high-voltage lines.

The paper shows that final standards in voltage are usually fixed by broad economic considerations rather than by physical limitations and suggests that 5000 volts direct current would offer a very satisfactory voltage for such a standard if commercial apparatus for this voltage were available. Finally, it touches briefly upon the operation of the experimental 5000-volt line at Jackson, Michigan, which has been so successful as to give great hope that the system will be commercially developed.

TEN YEARS ago, the idea that approximately 600 volts was the maximum potential to be hoped for in the operation of d-c. railways was almost as firmly established as was the belief in the days of Columbus that the earth was flat. On a few roads, it is true, 650 or even 700 volts was carried at the station and in an occasional rare instance, the use of a booster gave a maximum of 800 or 900 volts. Drop in the feeders, however, usually reduced these values considerably before they reached the car, so that these instances represented merely the generation of d-c. power at voltages above the nominal 600 rather than its utilization by the car motors.

Then suddenly the plan was suggested of coupling the four 600-volt motors ordinarily employed on interurban cars in pairs of two in series instead of two in parallel, and of connecting the generators in the stations in a similar manner, so as to employ

Manuscript of this paper was received March 9, 1916.

1200 instead of 600 volts. Two railways then under construction were willing to try the scheme, although there were some misgivings as to whether it would work or not; it did. The entire railway industry as a result has been given a lesson in open-mindedness which it should not soon forget and the use of d-c. voltages of from 1200 to 1500 for the operation of interurban railways has become so common that today we are able to discuss details of high-voltage d-c. practise.

Motors

Limiting ourselves for the time being to voltages of 1200 and 1500 in discussing the matter, the first element to be considered of a high-voltage car or locomotive equipment is of course the motor. As far as voltage between terminals is concerned, the requirements for motors to operate two in series on such voltages differ from the well-standardized designs for low-voltage service only in the fact that slipping of the wheels to which one of the two motors in series is connected may interfere with the normal voltage distribution between them and concentrate a large part of the total voltage at the terminals of one machine. Fear of this contingency at first led to the design of motors for high-voltage service with a much larger number of commutator bars than for corresponding 600-volt service. More extended experience, however, showed that such precautions were unnecessary.

Insulation and creeping distances on motors for high-voltage service must of course be made suitable for the full potential. This was accomplished at first by "main strength and awkwardness," as it were, and the limitations imposed by the extra insulation, extra creeping distances and extra commutator bars ordinarily carried with them a considerable sacrifice in capacity when a given motor was wound for operating two in series in 1200 volts instead of two in parallel on 600. As in the matter of commutator bars, however, wider experience gradually overcame this difficulty. The extra insulation required for 1200-volt operation is now obtained by the use of better quality rather than greater quantity of material, and the extra distances by improved shaping and arrangement of parts. Generally speaking, therefore, motors are produced today for use in series on 1200 or 1500 volts with the same dimensions and weights as if made for use on only 600 or 750 volts.

In referring to motors above, I have spoken as if the coupling of two 600- or 750-volt motors in series was the only arrange-

ment ever employed for utilizing 1200 or 1500 volts. There have been, however, one or two instances where motors have been wound directly for the full line potential. Speaking generally, such motors are heavier and depart more radically from standard low-voltage designs than motors for operating two in series, and moreover, they do not lend themselves as well to the operation of the cars partly on 600 and partly on 1200 volts as is so often required. In general, therefore, they seem to offer no particular advantages and are hence but little employed.

High-voltage d-c. railway practise, therefore, in the matter of motors may be said to consist in the use of two machines in series, these being identical in construction with standard motors for low-voltage service except in the comparatively minor details of quality of insulation and length of creeping distances.

Control

In control apparatus for high-voltage d-c. railway equipments, the fundamental requirements are to provide sufficient circuit-opening capacity to overcome the greater tendency to hang which the high-voltage arcs possess, together with the necessary means to confine these arcs within proper bounds.

The first result was secured in the early high-voltage apparatus by using two 600-volt switches in series at practically every circuit-opening point, and the second by liberal increases in the insulation and space surrounding all live parts. Thus our first 1200- and 1500-volt car equipments employed 13 pneumatically-operated switches, where with the same current at 600 volts eight would have been sufficient. The groups in which these switches were assembled, also, were approximately 24 in. (60.9 cm.) wide and 24 in. deep as compared with 18 in. (45.7 cm.) wide and 22 in. (55.8 cm.) deep for the corresponding 600-volt apparatus.

As with the motors, however, greater experience led to a reduction of these differences in the fundamental parts. Some of the extra switches in the first equipments came into play only when the controller was "backed off" from parallel to series, and by improvements in interlocking the work of opening the circuit at this time was transferred to another point so that these extra switches could be omitted. Another switch had been employed because it was feared that the high-voltage motors might require more careful handling and hence more resistance

notches than standard 600-volt motors. It was found later that such was not the case and this switch also was omitted in future equipments. In these ways, in the types of equipment most generally employed, the additional switches necessary on account of the increased voltage have now been cut down to two for small equipments or three for large ones. In dimensions also, it has been possible to work out designs for 1200-volt switch groups with the same cross-sectional area and the same weight per switch as those for 600 volts.

Auxiliary Control Devices. The introduction of the new element of operating at double voltage has greatly increased the number of possible combinations and alternatives which must be considered in any given case in order that they may be adopted or rejected.

In the first equipments for use on 1200 volts, it was considered undesirable to attempt to employ this voltage for the auxiliary circuits such as lights, control, air compressor, etc., and so a dynamotor was included as a part of the equipment to provide a supply of 600-volt current for such purposes. To reduce the capacity required of the dynamotor, the air-compressor motor was next wound for operating at full line potential, so that only the lighting and control circuits need be supplied at 600 volts. Even on this basis, the presence of the dynamotor in addition to the air compressor seemed unnecessarily burdensome, so that the next step was to combine the two machines in a dynamotor compressor. In this device, the air compressor, instead of being driven by a separate motor, as previously, is connected to or disconnected from the dynamotor when required by a suitable clutch controlled by the pressure governor. In locomotives or other equipments where forced ventilation is required, the operation is still further consolidated by mounting the blower fan on the shaft of the dynamotor so that the same machine in such cases serves a triple purpose. This offers considerable advantage in simplifying equipments, and the scheme of driving the compressor and providing 600-volt current for the auxiliary circuits from the same machine has become firmly established in high-voltage practise.

Where equipments are to be mounted on cars of small or moderate size, however, even this arrangement is somewhat of a handicap in the matter of cost and simplicity when comparison is made with the usual 600-volt equipment of the same capacity, so the next step was to arrange the lighting and control

circuits for operation directly from the line voltage. With electropneumatically-operated control, this was readily done and on such a basis, 1200- or 1500-volt equipments have been made practically as simple, reliable and easy to maintain as those for operation on 600 volts.

As the art now stands, these two general arrangements for handling the auxiliary circuits constitute a dual standard and one of the first decisions to be made in planning any given installation is between these two schemes.

Operation on Two Voltages. The most prolific source of vexatious problems is the use of equipments part of the time on low voltage and part of the time on high. As far as the main circuit apparatus is concerned, any high-voltage equipment will of course run on half voltage with a corresponding reduction in speed. In order that such operation may be satisfactory, however, special arrangements must be made to care for the auxiliary circuits.

Many interurban lines operate at high speeds over their own rights-of-way in the open country but enter one or more towns over the tracks of local 600-volt systems. High speed in the city is not permissible in any case and so approximately half of the normal speed when running on 600 volts is sufficient. For cars operating under such circumstances, it is common to provide for reconnecting the lighting and control circuits so that these will receive full voltage when the car is in the 600-volt section but so that the main motors will remain permanently coupled in series and thus operate at half speed.

If a dynamotor compressor is employed on cars which operate in this way, the same changes which are necessary in any case to care for the lighting and control circuits automatically care for the air compressor as well, connecting this for full speed on both voltages. In cases where approximately half speed on low voltage is sufficient for the main motors, however, the distances are usually short and half speed of the air compressor also is sufficient. Where cars which operate in this way employ a high-voltage compressor instead of a dynamotor compressor, therefore, no change is ordinarily necessary in its circuits for the low-voltage operation.

Since the motors on high-voltage cars are in general wound for only 600 or 750 volts each, the car can if desired be arranged to operate at full speed on both high and low voltage. Where this is required, a main change-over switch is employed which

connects the motors of each pair either in series for high voltage or in parallel for low voltage, and which connects the two halves of each step of the main resistance in a corresponding way. Suitable connections for air compressor, lights and control circuits can also be included in the same switch so that the setting of a single piece of apparatus into one or the other of two positions changes the car at once for use on high voltage or on low voltage.

When the proper scheme of operation on the two voltages has been decided, the next point to determine is the manner in which the change-over should be effected. The simplest method in either case of course is the use of a manually-operated switch on each car. It is sometimes desirable, however, to have the change-over switch located beneath the car and arranged for operation from the platform. In other cases, it is desirable to have the switches arranged not only for distant control in this way but also for simultaneous operation throughout a train of cars.

To supplement the apparatus for changing connections on equipments so that they may be operated on either high or low voltage, protective devices are sometimes desired to prevent or minimize the trouble which may occur in case a car is subjected to high-voltage when its change-over switch is arranged in the low voltage position. Such devices ordinarily consist of relays of some form which are so connected, when the change-over switch is in the low-voltage position, that they act quickly in case a voltage in excess of the normal is applied to the car, and cut off the circuits which are likely to be damaged.

The choice between automatic and non-automatic acceleration is not influenced particularly by the use of high voltages except that such voltages are more often employed for interurban lines where non-automatic acceleration is ordinarily considered preferable. The necessity for running on both 600 and 1200 volts in many cases also usually introduces certain complications in high-voltage equipments and there is a tendency to adhere to non-automatic control so that the simplicity of this will, as far as possible, offset the various complications which must be retained.

The use of field control or non-field control also is not particularly affected by the employment of high voltages except as influenced by the same general idea mentioned above with regard to the choice in the type of acceleration. For the sake

of simplicity, there is a tendency to adhere to non-field control to offset unavoidable complications at other points.

Alternatives in Control Apparatus. It will be seen from the above that even with common practise in high-voltage equipment fairly well standardized, a host of alternatives usually present themselves for settlement in almost every case. The most common questions are—should the voltage be 1200 or 1500; should the equipment be of the dynamotor compressor or of the non-dynamotor type; will it have to operate on high voltage only or on both high and low voltage; if required to operate on low voltage as well as high, will half speed be sufficient on main and compressor motors or will full speed on both voltages be necessary; must the change-over switch be arranged for indirect control or will manual operation be sufficient; if indirect control is required, can it be confined to the individual cars or will simultaneous operation throughout the train be required; is a protective device essential to guard against damage by the application of the wrong voltage or will this not be required? Other similar questions might be added to the list but these are the most important ones.

Most of these matters are largely influenced by the individuals who control the local situation, so that it is difficult to generalize with any degree of accuracy. As far as I can judge, however, current practise seems to be tending in the following directions.

Where the high-voltage cars must run over existing 600-volt lines to any considerable extent, the exact ratio between 600 and 1200 volts offers some advantages. Since high-voltage motors are made from existing standards also, there is a wider range of choice for 1200-volt operation than there is for 1500 volts, especially where small sizes of motors are required. So far, 1500 volts has been used in sections where 600-volt lines have been established only to a limited extent, that is, in comparatively virgin territory, while 1200 volts has been employed in sections where there has already been considerable 600-volt development. It seems probable that high-voltage practise will continue to follow these lines except in the case of the electrification of branch lines on steam railroads or similar instances where connections with existing lines will have little bearing.

Speaking broadly, the general tendency is toward the use of the dynamotor compressor on large expensive cars, particularly

where full speed is required on half voltage, since this arrangement lends itself readily to such operation. Dynamotor compressors also are particularly suitable for locomotives where forced ventilation is utilized. For smaller and less expensive rolling stock, non-dynamotor outfits are generally employed, although there is and always will be a certain amount of overlapping.

In the older sections of the country where distances of four or five miles must sometimes be run on city tracks, and where through cars over 600 volt lines are likely to be employed, equipments are usually required to operate at full speed on half voltage. Equipments for operating at half speed under these circumstances, however, offer considerable advantage in weight, cost and general simplicity and will undoubtedly find a considerable field where circumstances are favorable to their use.

Where large cars are arranged for full speed on both voltages, the tendency is toward the use of full speed for the air compressor also. On smaller cars where as a rule the compressor has more margin, half speed of this device is ordinarily thought sufficient even where the main motors operate at full speed.

In the matter of change-over switches, the general tendency is to employ the simple manually-operated type except where cars are operated at close headway or are constantly used in trains. In most cases, also devices to protect against the wrong voltage are not considered necessary.

Equipments with Drum Control. I have spoken in all of the above with particular reference to equipments using indirect or multiple unit types of control and primarily with reference to those using electropneumatic control. While high voltage equipments are occasionally used with drum type controllers, especially double equipments with rheostatic control where cars for city service are operated in small towns by interurban companies, the number of these is too small to warrant inclusion in any generalization such as that with which we have been dealing.

Power Supply

Direct-current power for high-voltage lines was first obtained by the use of two 600-volt generators, either engine- or motor-driven, connected in series. Since there was no particular object in retaining two generators in series such as there was for retaining two motors in series on the cars, generators for

delivering 1200 or 1500 volts directly were soon produced. At first these were of the ordinary commutating pole type. Such machines now, however, usually employ a compensating winding as well as commutating poles.

The next step in the production of high-voltage d-c. power was the use of two 600-volt, 25-cycle synchronous converters connected in series, and while this was considered a radical step at the time it was first proposed, the performance obtained was so satisfactory that single 25-cycle converters producing 1200 or 1500 volts on one commutator have now been developed and are in successful use. With 60 cycles, the maximum voltage so far employed from a single machine is 750 so that two machines in series are still required for high voltage lines. The performance on this basis, however, is most excellent.

Common substation practise for high voltage d-c. lines is now to employ single synchronous converters where power at 25-cycles is available, and to use either motor-generator sets or two converters in series, where 60-cycle power is employed. A particularly efficient substation arrangement on the latter basis is secured by installing three synchronous converters so arranged that any two of them may be connected in series. This gives a spare machine at a minimum expense. If a single bank of three transformers is used for supplying these converters, a spare transformer as well as a spare converter is also secured so that the station is prepared for almost any emergency.

Switching

In the matter of switching, the principal changes which have been made in handling current at 1200 or 1500 volts instead of at 600 volts have been for the purpose of insuring safety to the operators rather than for any other reasons. For this purpose, switchboard panels have been made higher than for 600-volt service and the circuit breakers located on them so as to be out of direct reach. For opening and closing the breakers, long wooden rods leading to insulated handles on the lower part of the panel, are provided. Where two or more breakers are located side by side, large barriers are placed between them to prevent any tendency to flash across. Knife switches have also been located out of reach in a manner similar to the circuit breakers and arranged with rods for distant control.

Line Construction

The first 1200-volt lines employed direct-suspension overhead trolley with a special form of porcelain insulators. The catenary form of construction offers so many advantages for such lines, however, that generally speaking, the most common practise is now to employ this. Several interurban lines are using 1200-volt third rail successfully for supplying power but the voltage surges to which this may give rise under certain circumstances, the difficulty of clearing a car in case of accident and the general safety hazard incident to the maintenance of a live conductor so close to the ground seem likely to limit the use of this form of construction.

A growing practise on high-voltage systems is that of carrying the feeders for a considerable distance from the station before tapping in to the trolley so as to limit the possible current flow in case of trouble of any kind on the cars. With the excellent voltage conditions which can so easily be secured on high-voltage lines, the slight sacrifice which need be made for the sake of protecting the substation apparatus in this way can usually be well afforded.

Economic Significance

In studying the development of 1200- and 1500-volt practise, the fundamental point which appeals to me is the ease, success and speed with which so radical a departure from previous practise has been carried out. In most developments of so far-reaching a nature, many sources of difficulty are usually overlooked at first and must be cared for in later apparatus at increased expense. In the high-voltage d-c. railway system, however, just the opposite has apparently happened. Many of the possible difficulties seem to have been over-estimated in importance and much of the trouble anticipated has failed to appear. It has therefore been possible to gradually simplify and cheapen the various fundamental parts which go to make up the system instead of having to follow the opposite and more usual procedure.

It is difficult to say whether this exceedingly gratifying condition was due to the more advanced engineering ability of the times, to the inherent simplicity of the d-c. railway apparatus, to the very excellent state which such apparatus for 600-volts had reached before its extension to higher voltages was attempted, or to the fact that the jump to 1200 or 1500 volts, while seemingly radical, really subjected the apparatus to conditions differing

comparatively little from those met with in 600-volt practise. Whatever the cause may have been, however, the result remains as a remarkable tribute to those who shared in its accomplishment.

The general results of the high-voltage d-c. system have been to make possible the construction of interurban lines or the electrification of branch steam railroad lines at considerably less expense for a given grade of construction than with 600 volts, or to render possible for a given expenditure the construction of lines capable of handling much heavier traffic. The usual practise has apparently been a compromise between these two possibilities, which has served to finally transfer the electric line from the street car to the real railroad class as far as transportation possibilities are concerned, while still maintaining the relationship and similarity with reference to the simplicity and reliability of the apparatus. With practically no greater expenditure for substations and feeders than the usual 600-volt trolley line, such roads are able to employ freight or passenger trains after the manner of steam lines in accordance with the needs of their business instead of having to restrict them on account of limitations in the distribution of power.

2400 and 3000 Volts

The comparative ease with which the use of 1200- and 1500-volt direct current was transferred from the realms of uncertainty to the list of every-day standards soon suggested the employment of still higher voltages. Inasmuch as the 1200-volt system had been brought about by the use of two 600-volt motors in series and as a few motors wound directly for this voltage had been produced with no particular difficulty, the obvious procedure was to continue the geometric progression and connect 1200-volt motors and generators in series so as to operate at 2400 volts.

From a technical standpoint, there was apparently no particular difficulty in doing this, and one line installed on this basis has had a remarkably successful record. From a general standpoint, however, while the results have been welcome as a contribution to the development of the art, suitable applications for this particular voltage are apparently somewhat lacking. For trolley roads of the usual interurban class, it has the inherent disadvantage of requiring apparatus which departs too widely from the existing standards with which the

operating forces have become familiar, as well as of not lending itself to interchangeable operation over 600-volt lines. For heavy traction, on the other hand, this voltage is much too low to solve the problem in a sufficiently comprehensive way to attract the investment of capital in electrification. Even 3000 volts, while overcoming the latter disadvantage to some extent, does not do so completely. It is regrettable also that *both* 2400 and 3000 volts have been employed and that in carrying on the upward progress in d-c. voltages, 1500-volt apparatus was not used at once for coupling in series, for carrying on the geometric progression, without the intermediate 2400-volt step.

Ultimate Limits of D-C. Voltage

The general limits upon which standard practise in any industry ordinarily settles are usually fixed by broad economic considerations rather than by physical limitations. It is entirely possible for instance to operate trains at maximum speeds of 90 miles per hour or more, yet the maximum ordinarily attained is from 60 to 80 miles per hour. Physically speaking, also, interurban cars can be run at speeds similar to these, yet the general average on such roads is from 50 to 60 miles per hour. These values have been established by gradual increases from lower ones until without any conscious effort, standardization has been automatically secured.

In the voltages which may be employed with the d-c. railway system, there is some tendency toward this same procedure. If no efforts were made to the contrary, it is not improbable that starting from the voltage of 3000, which we have today on the Chicago, Milwaukee & St. Paul, we would next hear of the employment of 3600 volts, then possibly 4200 volts and so on up in corresponding steps. Sooner or later, however, a point would be reached where, by common consent, these increases would stop just as this has happened in the matter of speeds.

While in a way, such a procedure would be the conservative and natural way for progress to come about in the use of higher d-c. voltages, its disadvantages are too obvious to require mention. The apparently more radical plan of trying to select in advance the voltage at which such increases would naturally stop and of going at once to this voltage would hence seem to be the more rational and really the more conservative as far as the general good of the industry is concerned. It has been

with this idea in view that our efforts toward the use of direct current at 5000 volts are being put forth. With practical apparatus for this voltage available, the problems of distributing and collecting the necessary power for the largest locomotives likely to be required can be readily solved so that although further increases might be possible, they should be entirely unnecessary.

Operation of 5000-Volt Equipment

The general construction of the 5000-volt experimental equipment on the Grass Lake line of the Michigan United Traction Co. and the results of its first few months' operation have been so widely covered by the technical press that it is unnecessary to refer further to them except to say that the equipment is still in operation on the same successful basis, and that at the time this is written, it has run a little over 30,000 miles. During the five months from October 1st to March 1st, the car averaged 5295 miles per month on a schedule which allows only 15 miles per hour and its record would have been even greater than this had it not been for numerous mechanical difficulties with the trucks, wheels, brake rigging, stove, pilots and other mechanical parts of the car for which the equipment was in no way responsible. During the four months of November, December, January and February, which, on account of weather conditions, are ordinarily considered the worst in the year, the car ran 23,320 miles or an average of 5830 per month.

During this period the car operated through severe snow, sleet and rain storms and for a short period even ran with two of the commutator covers missing, these having been lost on the road. The motors and control were purposely allowed to go with a minimum of cleaning and other care, and various reports sent in by the men in charge refer to the presence of wheel wash, dirt and other obnoxious substances in the motors and switch groups, although no damage was caused by them.

A half-dozen or so failures have occurred during the winter but these have been mostly in the nature of broken motor leads or similar troubles which served merely to test the practicability of the use of such a voltage under the general rough conditions to which car equipments are subjected rather than to indicate any inherent weakness. These troubles showed that this equipment could as easily withstand such ordinary mishaps

as any equipment for 600 volts. Only two of the failures were in any way due to the use of 5000 volts and these consisted of grounds on the grid resistance which took place through the water-soaked flame-proof covering on certain of the leads where the cables had not been properly insulated and supported. Such troubles can be easily guarded against on new equipments.

While as yet only the one equipment now in experimental operation has been built, various designs of other sizes have been considered and with the special double armature type of motor and double jaw type of switch which have made this equipment possible, unusual flexibility in meeting a wide range of conditions can apparently be obtained.

In most of the considerations of the use of d-c. voltages of 2400 and 3000, there has always been a certain minimum size of motor which could be economically produced and this size has been undesirably large for certain classes of service. With the special double armature type of motor for 5000-volt equipments, however, the experimental equipment already in use is about as small as would ordinarily be required, although even this is apparently not the minimum limit. On the other hand, the design seems equally adaptable to large sizes.

Conclusion

Broadly viewing the high-voltage d-c. practise which we find today, and its significance to the industry, there are four ideas which appeal particularly to me. The pernicious flexibility of the 1200- and 1500-volt systems and the innumerable alternatives which they present for application to any definite case in interurban work seem to give timely warning of the great desirability of early standardization in the matter of higher d-c. voltages. The comparative ease with which apparatus for these voltages has been developed gives a most encouraging feeling for further development along the same lines. The possibilities which a d-c. system at 5000 volts would offer were the apparatus commercially available make this voltage seem a logical one, and the results obtained with the experimental equipment now in operation give great hope that this voltage may some day be established commercially as a standard of high-voltage d-c. railway practise.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

(*Subject to final revision for the Transactions.*)

EFFECT OF BAROMETRIC PRESSURE ON TEMPERATURE RISE OF SELF-COOLED STATIONARY INDUCTION APPARATUS

BY V. M. MONTSINGER

Abstract of Paper

The paper falls logically into three divisions: (1) A general review of the principal laws of the dissipation of heat,—radiation, conduction and convection. (2) the development of a simple formula for the effect of altitude on the cooling of surfaces of different shapes, and (3) a general discussion of the method of conducting experimental observations at different altitudes, on three different shaped surfaces.

1. The first division is principally historical in that the most reliable data is given as found from former laboratory investigations, to determine (a) the laws of heat dissipation and (*b*) the effects of various factors on these laws. This is given as a preparatory step to determining the formula in division 2.

2. It is shown in the second division that, where the loss by convection varies as the 1.25 power of the temperature rise and as the 0.5 power of pressure, the " temperature rise " varies as the 0.4 power of pressure. It is then shown that the temperature rise increases, in going from a lower to a higher altitude, at a uniform rate of about 5 per cent for each 1000 meters change in elevation.

Since this applies only to loss of heat by convection, a correction factor is added to reduce this effect when radiation (same in vacuo as in gas) enters into the dissipation of heat. This factor is first expressed in percentage of convection loss to total loss, and then expressed in terms of the developed surface effective for convection, and the envelope surface effective for radiation. This is called the " shape-factor" S. The percentage increase in temperature then is equal to $5\ A S$ where A is the difference in altitude expressed in kilometers.

The above is for a loss unaffected by temperature. Where the loss is in copper windings, an increase in temperature, due to changes in pressure, has the effect of increasing the loss, which in turn still further increases the temperature rise.

It is shown by mathematical treatment that this effect increases the value $5\ A S$ to $5.85\ A S$ for all copper loss. For various ratios of copper to iron loss (unaffected by temperature), the term becomes, close enough for practical purposes, $A S\ (5 + a)$, where a is percentage of copper loss to total loss. The calculated values are then compared with the observed values.

3. In this division the method of carrying on the experimental observations is gone into somewhat in detail.

Introductory

While we have reliable data, obtained from laboratory investigations, on the effect of rarefied atmospheres on each of the three principal modes of heat dissipation—radiation

Manuscript of this paper was received March 15, 1916.

conduction and convection,—yet there does not seem to be any data on, or record of, an investigation to determine this effect when various combinations of the above modes enter into the dissipation of heat, such as we usually have in self-cooled induction apparatus.

Since there is a wide range of these combinations, it would be impossible to make experimental observations on each one. Tests conducted on a few combinations should give us sufficient data with which to make calculations for the remaining ones. Calculations, of course, can be made only by making use of the known effect of altitude on each mode entering into the dissipation of heat; and at the same time we must know fairly accurately

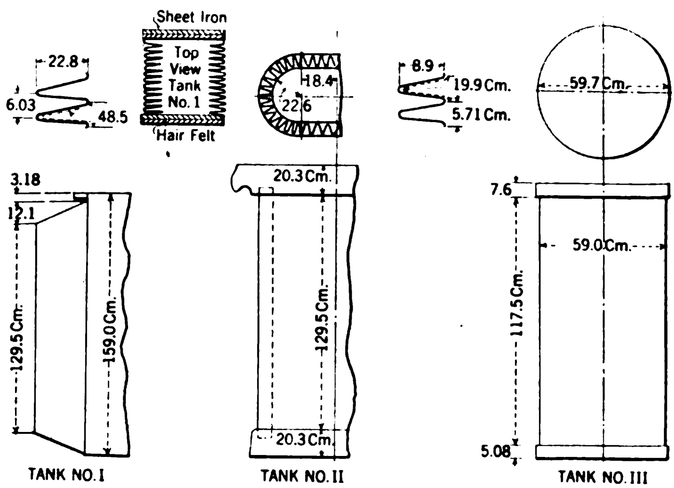


Fig. 1

the proportion of heat emitted by each mode, *i.e.*, we should know its law.

The law of radiation has been accurately determined by Stefan and Boltzman, whence it derives its name, "Stefan-Boltzman law." The law of conduction is well known but need not be considered in this discussion because rarefied atmospheres do not affect it, and for stationary electrical apparatus the dissipation of heat takes place almost entirely by radiation and convection, the latter, excepting for plain surfaces, playing the more prominent part. A law for the convection of heat has been developed and is given by Dr. Irving Langmuir in some of his publications.* While this law holds remarkably well for high

*Proc. A. I. E. E. Feb. 1913, Amer. Electrochem. Soc. Apr. 1913.

temperatures, yet for low temperatures, *i. e.*, from 0 to approximately 100 deg. cent., it does not seem to hold very well. This is shown later and in fact is pointed out by Dr. Langmuir himself.

The object of this paper is (1) to give, as found from experimental observations on surfaces of various shapes, the ratio of heat dissipated by radiation to that dissipated by convection, thus making it possible to predict the effect of altitude on the cooling of surfaces of different shapes, such as are found in stationary electrical apparatus, and (2) to give the results of experimental observations conducted on transformers (Fig. 1) under natural atmospheric conditions at different altitudes ranging from 305 m. (1000 ft.) to 3360 m. (11,000 ft.) These observed values are compared with theoretical calculations, making use of the established laws of the effect of barometric pressure on the principal modes of heat dissipation, namely, radiation, conduction and convection. From this a simple formula is developed, expressing the effect of altitude on the cooling of surfaces of various shapes.

GENERAL LAWS OF RADIATION, CONDUCTION AND CONVECTION OF HEAT

Radiation of Heat

The Stefan-Boltzman law that the radiation from a black body is proportional to the difference of the fourth powers of the absolute temperatures has withstood very rigid experimental investigations and can be considered as accurate. The Stefan-Boltzman law as applied to the radiation of heat from a body may be expressed

$$W_r = K\,e\,(T_2^4 - T_1^4) \qquad (1)$$

where W_r = watts radiated per sq. cm. of surface.
K = an empirical constant.
e = relative emissivity which depends on the nature and color of the surface.
T_2 = absolute temperature of the radiating surface.
T_1 = absolute temperature of the room.

The exact value of K has not been definitely determined at present, but 5.7×10^{-12} (probably the most commonly accepted value) has been used in making calculations to check the experimental observations on surfaces of various shapes. To quote from Dr. Langmuir (Trans. A. I. E. E. Vol. xxxii, 1913 p. 309.)

The radiation constant, 5.7, is subject to some uncertainty at present. For several years, the commonly accepted value was 5.32, which was the result obtained by Kurlbaum (*Wied. Am.* 65, 746, 1898). Recently, however, (1909), Fery obtained a value 6.3. Since then many investigators have redetermined this constant. Paschen and Gerlach (*Ann. d Physik*, Vol. 38, p. 30, 1912) obtained the value 5.9. Shakespeare (*Proc. of the Roy. Soc.*, Vol. 86A, p. 180, 1911) obtained 5.67. Within the next year or so the correct value of this constant will undoubtedly be determined. For the present, it would seem almost certain that the value 5.32 is too low, and that the value 5.7 must be fairly close to the true value.

Effect of Pressure, Color and Contour of Surface on Radiation

Since radiation of heat is purely a surface phenomenon, it is proportional only to the envelope of the surface and is independent of the pressure of gas. In other words, for a surface of an irregular contour it is the outer area, that is effective for radiation, and the rate of radiation is the same in vacuo as in a gas, all other conditions being the same.

For surfaces that are not black the heat radiated is always less than that of a perfect black body. The following tabulation, by Langmuir, taken from Table VII Trans. of the Am. Elec. Soc. Vol. 23-193, gives in part for various colored surfaces the relative emissivities e as percentage of that from a black body.

	Relative Emissivities e			
Temperature deg. cent. (room 27 deg.)	52	77	127	mean
Copper oxidized	77	70	76	74
Copper calorized	39	28	26	31
Silver (calculated)	1.7	1.9	2.1	1.9
Cast iron bright	17	20	23	20
Cast iron oxidized	50	67	64	60
Aluminum paint	67	60	45	57
Gold enamel	33	40	37	37
Monel metal bright	50	55	38	47
Monel metal oxidized	50	60	49	56

Again, if a surface is irregular such as we have in corrugated tanks for self-cooled transformers and the color is considerably different from a perfect black, the heat radiated from the cavities is greater than that radiated from a flat surface. This is due to the fact that besides the heat dissipated by direct radiation, additional heat is thrown out by reflection. However, the color

of the surfaces of the tanks used by the writer in the experimental observations (and also for practically all commercial transformers) was practically a lamp black, and e has been considered as unity, *i.e.*, no attempt has been made to make corrections for the color when making theoretical calculations. A small error may have been introduced due to this effect, but in general for surfaces of this color the error should be negligible.

Conduction of Heat

Since conduction of heat takes place by transference from one part of one body to another part of the same body without bodily transfer, this mode of heat transmission has very little, if any, effect on the change in temperature of stationary induction apparatus due to changes in barometric pressures. In other words, it is not necessary to consider it in this discussion. In general, however, for a steady flow of heat through a solid of uniform material the following law holds:

$$W \doteq \frac{KA}{l} (T_2 - T_1) \tag{2}$$

Where W = watts of heat flow
K = coefficient of heat conductivity
A = area of cross section
l = length of conductor
$(T_2 - T_1)$ = temperature difference causing flow of heat.

Convection of Heat

Within the last four or five years Dr. Langmuir has done considerable work upon, and has developed a formula for, the convection of heat. His formula is based on the film theory, in which he assumes that the dissipation of heat takes place by first being conducted through a film of adhering gas, to the surrounding medium where it is carried away by convection air currents. The formula is expressed in the form

$$W_c = \frac{\phi_2 - \phi_1}{B} \tag{3}$$

Where W_c = Watts dissipated per sq. cm. surface
B = thickness of adhering film

and ϕ is a function of T (the absolute temperature) of the form

$$\phi = 1.93 \times 10^{-5} (1 + 0.00012\ T) \left[2/3\ T^{3/2} - 248\ T^{1/2} + 2760\ \tan^{-1} \sqrt{\frac{T}{124}}\ \right]$$

From experimental observations, Dr. Langmuir found that for temperatures greater than 100 deg. cent. the value of B is 0.45 cm. Observations made throughout a wide range of high temperatures agree remarkably well with calculations using this empirical constant; but for low temperatures, of approximately 100 deg. cent. and less, he found it necessary to give B values greater than 0.45 cm. For example, for a 25 deg. cent. rise above 27 deg. room temperature, B had the value of 0.58 cm. and for temperature rises between 25 deg. cent. and 75 deg. cent. B ranged between 0.45 cm. and 0.58 cm. Since 0 deg. to 100 deg. cent. usually covers the temperature range found in self-cooled induction apparatus, this formula would not give correct results unless supplied with different values of B for different temperature values.

In 1817, Dulong and Petit announced the following law as a result of their experiments conducted over a rather limited range of temperatures.

> The velocity of the cooling due solely to the contact of a gas is proportional to the excess of temperature in degrees centigrade raised to the power 1.233.

This was later verified by Peclet.

Lorenz (*Ann. d. Physik*, Vol. 13, p. 582, 1881) by making certain assumptions derived for convection of heat from vertical plane surfaces the following formula:

$$W_c = 0.548 \sqrt[4]{\frac{c\ g\ K^3}{h\ H\ \theta_1}}\ \rho^{0.5}\ \theta^{1.25} \qquad (4)$$

where W_c = heat convection per sq. cm. of surface
c = specific heat of gas at constant pressure
K = its thermal conductivity
h = its viscosity
θ_1 = its average temperature in deg. cent.
ρ = its average density
g = gravitational constant
θ = difference in temperature of plane surface and of the gas at a great distance from the plane.
H = height of plane.

For 30 deg. cent. room temperature and for standard atmospheric pressure the above formula reduces to

$$W_c = 3.98 \times 10^{-4} H^{-\frac{1}{4}} \theta^{1.25} \quad (5)$$

The results of observations conducted by the writer indicate that the loss vs. temperature rise follows a simple exponential law similar to Lorenz' formula (when H = approx. 9 cm.) throughout a range of temperatures from 0 deg. cent. to approximately 100 deg. cent. (tests were not made above 100 deg. cent.). This was first found in plotting on logarithmic paper,

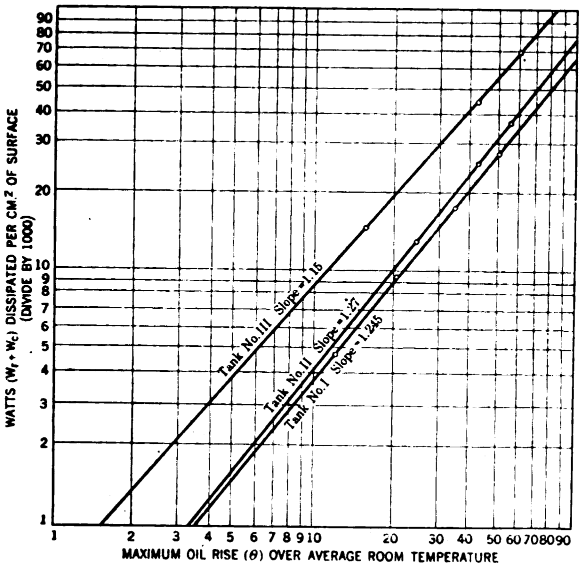


FIG. 2

the maximum oil rise of tanks with surfaces of various shapes against the loss dissipated per unit area of developed surface. Referring to Fig. 2 in which maximum oil temperature is plotted on a logarithmic scale against loss per unit area of the developed surfaces of three tanks shown in Figs. 3 and 4, it will be noted that these points fall (for each tank) practically in a straight line. Providing the temperature gradients along the tank surfaces from top to bottom do not change for different maximum oil rises (and there is no reason why they should appreciably change) the equation of the line drawn through these points for any one tank, when supplied with the proper constant, (found

by trial), gives us the law of heat dissipation for that particular tank. This equation, however, includes here both radiation and convection.

Using an empirical formula for convection somewhat similar to equation (**5**), calculations indicate that tank No. 1 dissipated approximately 85 per cent of its loss by convection and 15 per cent by radiation; that tank No. II dissipated approximately 65 per cent of its loss by convection and 35 per cent by radiation; while tank No. III (plain), dissipated approximately 43.5 per cent of its loss by convection and 56.5 per cent by radiation.

The equation based on maximum oil rise for tank No. I should therefore be that, or nearly that, for the loss of heat by convection since a very small percentage of its loss was dissipated by radiation. The slope of this line is 1.245 or

$$W_c = K\theta^{1.245} \tag{6}$$

where W_c = watts dissipated per unit area of surface
K = constant (determined empirically)
θ = maximum oil rise above average room temperature

It will be noted that the above exponential value agrees remarkably well with that found empirically by Dulong and Petit (1.233) and also with that calculated by Lorenz (1.25). The writer finds that this formula holds very closely for maximum oil rise of tanks with various types of irregular surfaces, ranging from surfaces of simple corrugations to surfaces that are very complicated.

The equation of the line for tank No. II is

$$W_c = K\,\theta^{1.27} \tag{7}$$

and for tank No. III (plain surface)

$$W_c = K\,\theta^{1.15} \tag{8}$$

If we take from Fig. 6 (radiation curve) the temperature rise line based on 30 deg. or 35 deg. cent. room temperature and plot it on logarithmic paper, we obtain, between the limits of 10 deg. and 50 deg. rise, a line whose equation is approximately

$$W_r = K\,\theta^{1.12} \tag{9}$$

The exponent in equation (**8**) which involves approximately equal values of radiation and convection falls between the values 1.12 and 1.245, as would be expected. However, the temperature range from which equations (**7**) and (**8**) were based is not as wide

as that on which equation (**6**) is based and for this reason they are probably not as accurate. Refering to Fig. 2, it will be noted that equation (**6**) is based on four observed points. The lower one was obtained in Pittsfield only for the purpose of determining a more accurate exponential value, and therefore this test was not repeated at the higher altitudes. For temperatures within the range of the operation of stationary induction apparatus, the convection for vertical surface can no doubt be expressed within a reasonable accuracy by the simple equation

$$W_c = K\,\theta^{1.25} \tag{10}$$

where W_c = watts dissipated per sq. cm. of surface

K = constant (found by trial to be 2.32×10^{-4} for tanks No. II and III and 2.04×10^{-4} for tank No. I)

θ = temperature rise in deg. cent.

It is interesting to note that when we substitute 9.0 cm. for H in Lorenz' equation, it becomes

$W_c = 2.3 \times 10^{-4}\,\theta^{1.25}$ which is practically the same as equation **10**.

Equation (**10**) is used later in comparing calculated values of loss by convection with the input loss less the calculated loss by radiation for three different styles of tanks. Also it is used in deriving a formula for expressing the effect of altitude on the cooling of surfaces of various shapes. It should be noted that it is not intended that this formula be applied for high temperatures where the formula $\frac{\phi_2 - \phi_1}{B}$ holds, but only for low temperatures of 100 deg. cent. and less.

Effect of Room Temperature on Dissipation of Heat

(*a*) *Radiation*. Referring to Fig. 6 it will be seen that room temperature has an appreciable effect on radiation. For example, for a 50 deg. rise the loss radiated in the presence of a 15 deg. cent. room temperature is 0.0354 watts per sq. cm., while in a 35 deg. cent. room temperature, the loss is 0.0427 watts per sq. cm.—a difference of 20 per cent, or 1 per cent per deg. variation in room temperature. For this reason an attempt was made to hold as nearly as possible the same room temperatures at the three different altitudes.* The room temperatures were the same at both Pittsfield and Leadville, while, due to encountering a period of very warm weather at

*See p. 473 for locations.

Boulder, it was necessary to hold a room temperature from one to six degrees higher than that held at the other two places.

(*b*) *Conduction.* Room temperature should have no effect.

(*c*) *Convection.* According to Dr. Langmuir's equation, $\frac{\phi_2 - \phi_1}{B}$, (plotted in Fig. 5) room temperature has very little effect on convection. No attempt has been made to add a room temperature correction factor in equation (**10**).

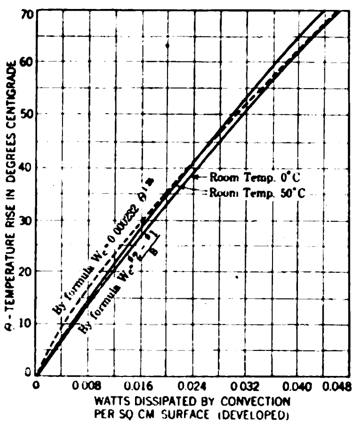


FIG. 5

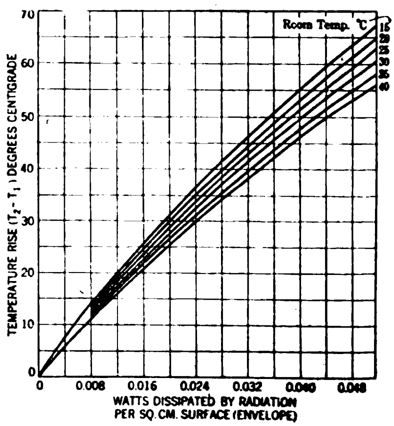


FIG. 6

Effect of Barometric Pressure on Radiation Conduction and Convection

(*a*) *Radiation.* Since radiation does not depend on the density of the surrounding air, changes in barometric pressure have no effect on it.

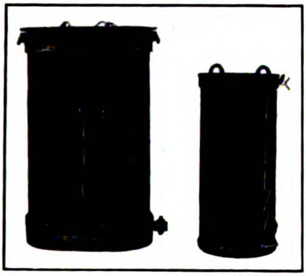
(*b*) *Conduction.* Changes in pressure do not affect conduction.

(*c*) *Convection.* In 1817 Dulong and Petit found that the velocity of cooling in a gas was proportional to the pressure raised to the power

0.45 for atmospheric air.
0.38 for hydrogen
0.517 for carbonic acid.
and 0.501 for olifiant gas.

Messrs. Kennelly and Sanborn* in an investigation on "The

**Proc. Am. Phil. Soc.* Vol. liii, 1914.



[MONTSINGER]

FIG. 3—CORRUGATED AND PLAIN TANKS USED FOR HEAT TESTS TO DETERMINE EFFECT OF BAROMETRIC PRESSURE ON TEMPERATURE RISE OF SELF-COOLED TRANSFORMERS

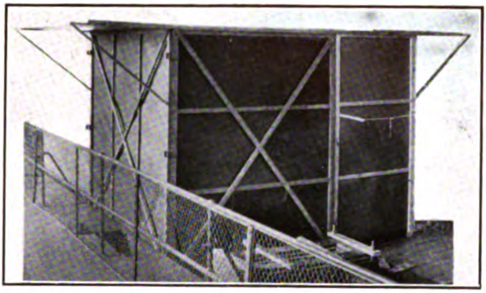


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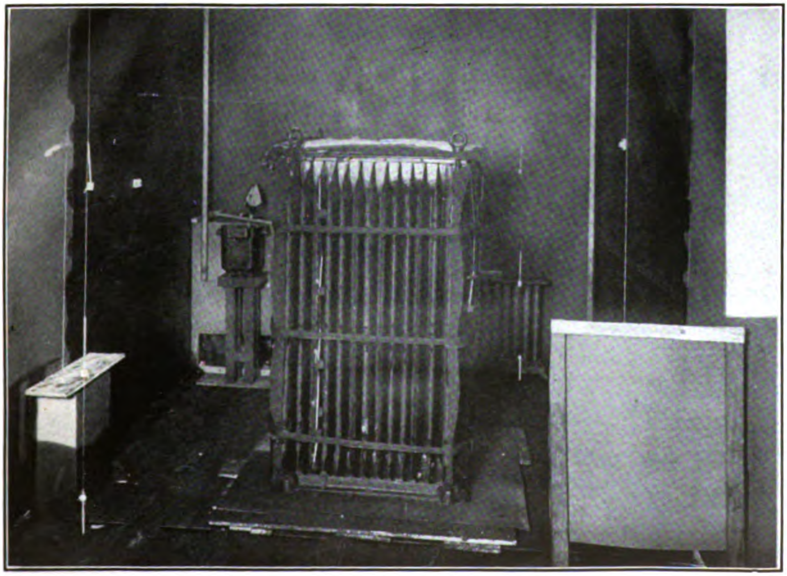
FIG. 8—PRESSBOARD HOUSING USED FOR MAKING TESTS TO DETERMINE EFFECT OF BAROMETRIC PRESSURE ON TEMPERATURE RISE OF SELF-COOLED TRANSFORMERS



[MONTSINGER]

FIG. 4—SHOWING TANK NO. 1 IN HEAT RUN POSITION

Influence of Atmospheric Pressure upon the Forced Thermal Convection from Small Electrically Heated Platinum Wires," found that the linear convection is nearly proportional to the 0.5 power of the atmospheric pressure.

Compan found that for spheres 2 cm. in diameter, convection varies as the 0.45 power of the pressure. According to Lorenz' equation, convection varies as the 0.5 power of the pressure. In making calculation later on, the writer has used the value 0.5.

Effect of Position, Shape of Contour, and Height of Plane on Convection

Dr. Langmuir found that the convection was about 10 per cent more for the upper, and 50 per cent less for the under side of a horizontal plane than for a vertical plane. (Note: the covers for the tanks used in the experimental observations were insulated thermally from the horizontal surfaces so that practically no heat was lost by them, thus eliminating the necessity of making corrections when comparing input with calculated loss.)

Calculations indicate that the convection is practically the same for a plain surface, 130 cm. (51 in.) in height as for a surface having corrugations 8.9 cm. (3.5 in.) in depth, 5.72 cm. 2.25 in.) pitch and 130 cm. (51 in.) in height; but that the convection is approximately 15 per cent less for a surface having corrugations 22.8 cm. (9 in.) in depth, 6.03 cm. (2 3/8 in.) pitch and 140 cm. (55 in.) in height with upper and lower air spaces open for free circulation of air.

Again according to Lorenz's equation, convection varies inversely as the height of a vertical plane raised to the $\frac{1}{4}$ power ($H^{-1/4}$). Observation of tests made on vertical surfaces whose heights range from one or two meters to four or five meters indicate that the $\frac{1}{4}$ power is too large. In fact experience indicates that for simple corrugations and for heights ordinarily used for cooling of stationary induction apparatus, the effect of height is practically negligible. As an evidence that the $\frac{1}{4}$ power of the height is too great, if we substitute 130 cm. (corresponding to the heights of tanks used in the observations)for H in Lorenz's formula it becomes:

$$W_c = 1.18 \times 10^{-4}\ \theta^{1.25}$$

Referring to equation (10) it is seen that if we had used Lorenz's formula the calculated loss would have been only about 50 per cent of the loss actually found in the observation. But

as pointed out before for a height of 9 cm. the formula gives practically the same results as equation (**10**).

Method of Calculating Loss Dissipated from Tank Surface

For theoretical calculations, the temperature of the surfaces having corrugations was taken as an average of the temperature of the outside and inside bends. If the equations for radiation and for convection were not in exponential form, *i.e.*, if loss plotted against temperature rise were straight lines, it would only be necessary to determine the average temperature of the surface and this multiplied by the areas would give us the predicted losses by convection and by radiation. Again if we had an equation of the temperature gradient from the top to the bottom of the surface of each tank we could substitute in the general heat equations and integrate between limits, for calculating the losses. However, it would probably be a long and tedious task to derive an equation for the temperature gradient of the surface.

The most convenient method, (and the one used by the writer) is to use the process of summation, *i.e.*, to divide the area of the surface into sections for every few deg. rise, and calculate the loss for each section separately. The sum of the losses for the sections should be the total calculated loss. If the surface is divided into enough sections the error introduced is small.

Table I shows a comparison of the input loss (at Pittsfield) with calculated losses using the equations:

$$W_r = 5.7 \times 10^{-12} (T_2^4 - T_1^4) \qquad \text{for radiation}$$
$$W_c = K\,\theta^{1.25} \qquad \text{for convection}$$

and

$$W_c = \frac{\phi_2 - \phi_1}{0.45 \text{ cm.}} \qquad \text{for convection.}$$

The table shows, with the exception of the plain tank, that the equation $\frac{\phi_2 - \phi_1}{B}$ gives too high loss at lower temperatures, but that as the temperature increases the calculated and test values come close together, which indicates, as pointed out before, that B has a greater value than 0.45 cm. for low temperatures. For the plain tank the losses are so small, especially for test 7 that a few watts in observable errors would make a large error in the calculation.

TABLE I.

COMPARISON OF CALCULATED LOSS WITH TESTS CONDUCTED AT PITTSFIELD.

Test	Max.* oil rise deg. cent.	†Ave. test watts input	Input watts less calc. by rad.	Watts loss by convection calculated by equations $W_c =$		
				$\frac{2.04\,\theta^{1.25}}{10^4}$	$\frac{2.32\,\theta^{1.25}}{10^4}$	$\frac{\phi_2 - \phi_1}{0.45 \text{ cm.}}$
		TANK No. I.				
1	21.1	1564.5	1268.0	1245.0	1413.0	1757.3
2	34.6	2910.0	2370.0	2380.0	2709.5	2985.0
3	50.9	4721.0	3811.0	3830.0	4461.0	4561.2
		TANK No. II.				
4	24.9	1550.	1023.4	......	1005.0	1266.
5	42.3	3114.0	2114.0	......	2011.0	2297.0
6	56.7	4500.0	3026.2	......	3129.0	3200.0
		TANK No. III.				
7	15.6	347.5	186.5	......	100.0	144.
8	41.9	1064.5	478 0	......	446.5	480.0
9	60.2	1657.5	704.5	......	722.3	735.1

*Based on the following average ambient temperatures:

For tests No....................	1	2	3	4	5	6	7
Room (deg. cent)................	30.0	30.1	32.0	30.0	32.0	32.0	29.9
Test No.....................	8	9					
Room (deg. cent.)............	30.2	30.1					

†Ave. of volt × ampere and wattmeter readings.

THEORETICAL CALCULATION OF EFFECT OF PRESSURE ON COOLING

We now have sufficient data with which we should be able to predict very closely the increase in temperature of self-cooled stationary induction apparatus. Assuming that the loss dissipated by convection W_c varies as the 0.5 power of the barometric pressure, and as the 1.25 power of the temperature rise, and letting ρ equal the barometric pressure in mm. of mercury, the general equation for convection becomes

$$W_c = K\,\theta^{1.25}\,\rho^{0.5}$$

or $$\theta^{1.25} = \frac{1}{K}\,\frac{W_c}{\rho^{0.5}}$$

$$\theta = K_1\,\frac{W_c^{0.8}}{\rho^{0.4}}$$ or compared with ρ at sea level

$$\theta = K_1\,W_c^{0.8}\left(\frac{760}{\rho}\right)^{0.4}$$

For a constant loss the temperature rise therefore varies inversely as the 0.4 power of the pressure.

Using the Smithsonian Institute's formula changed from English to metric system for altitude vs. barometric pressure, namely

$$\log_{10} \rho = \log_{10} 760 - \frac{A}{19.07377\,[1+0.00367\,(T-10)\text{ deg. cent.}]} \quad (11)$$

where

ρ = barometric pressure in mm. of mercury.
A = altitude in kilometers.
T = temperature in deg. cent. = 30 deg.

we obtain the following values:

when ρ	=	760	711	664	621	570	542	507	474 mm.
or 1,000 A	=	0	600	1200	1800	2400	3000	3600	4200 m.
% increase in θ	=	0	2.72	5.6	8.75	11.4	14.60	17.52	209
$\frac{\%\text{ increase in }\theta}{A}$	=	0	4.53	4.66	4.86	4.86	4.86	4.86	4.97

The average of the above values is 4.8. With an average positive error (when A is greater than 1.2) of about 2.5 per cent, we may put

$$\phi_1 = 5\,A \quad (12)$$

where ϕ_1 is the percentage increase in temperature for a constant loss and A is the difference in altitude between lower and upper elevations expressed in kilometers (*i.e.*, for 1000 m. A = 1).

Effect of Pressure on Surface Dissipating Part of Loss by Radiation and Part by Convection

Equation (**12**) is applicable only for a surface dissipating all its loss by convection when naturally cooled. However, this condition seldom exists in commercial transformers.* The percentage of total loss by convection is probably from 40 to 45 per cent for a plain surface, whereas for surfaces with very complicated contours the loss by convection may approach more nearly 100 per cent. It follows, therefore, that the effect of altitude will be quite different for different types of surfaces—each one requiring special consideration.

This effect may be expressed in terms of the percentage of

*Natural draft transformers would come under this condition where the total RI^2 loss is carried away by natural circulation of air through ventilating ducts in the windings.

loss by convection to the total loss. For example, if only 50 per cent of the loss is by convection and the remaining by radiation (unaffected by pressure) the effect of pressure will be approximately one-half that expressed by equation (**12**). Letting ϕ_2 equal the percentage increase in temperature rise for surfaces having both radiation and convection, we have

$$\phi_2 = 5\,A \times \frac{\text{loss by convection}}{\text{total loss}}$$

or

$$\phi_2 = 5\,A \times \frac{W_c}{W_c + W_r} \tag{13}$$

where W_c is the convection loss per unit area of developed surface and W_r is the radiation loss per unit area of envelope surface.

Since the ratio between W_c and $(W_c + W_r)$ does not remain quite the same when the altitude changes, equation (**13**) is not quite correct. For instance, when the apparatus is taken to a higher altitude the radiation increases while the convection may decrease. However, the error is small especially for surfaces with irregular contours such as corrugations, etc., where the greater part of the loss is by convection, and since it is a positive error, *i. e.*, it makes the estimated temperature rise slightly higher than it should be, it may be neglected for practical purposes. An attempt to correct for it would require an equation very cumbersome to handle.

If we assume a standard room temperature and a standard temperature rise, we can, for practical purposes, express W_c and W_r in terms of the developed and envelope surfaces reduced to equivalent values of loss per unit area. This makes it more convenient for practical application. For example, referring to Figs. 5 (either formula for convection) and 6 we find that for a 50 deg. rise above a 30 deg. room temperature the calculated watts dissipated per sq. cm. of surface are approximately in the ratio of 1.0 for convection to 1.3 for radiation.

We may therefore restate equation (**13**)

$$\phi_2 = 5\,AS \tag{14}$$

where S = shape factor = $\dfrac{\text{developed surface of tank}}{(\text{dev.} + e\;1.3 \times \text{envelope})\ \text{surfaces.}}$

Derivation of General Equation for Effect of Barometric Pressure on Temperature Rise

We have seen that for temperature rises between 0 deg. and 75 deg. cent., the general equation of temperature vs. loss is $\theta = K W^n$ and that the equation of temperature vs. altitude is $\phi_2 = 5 AS$. If we let θ = temperature rise at some high altitude

let W_0 = loss at room temperature θ_0 for given load conditions on the transformer

" W = loss at temperature rise θ

" $a = \dfrac{\text{copper loss}}{\text{(iron + copper) loss}}$

We have $W_0 = W_0 (1 - a) + a W_0$

Since iron loss is practically unaffected by temperature (see Proc. A. I. E. E., Oct. 1912, MacLaren) at temperature θ (for temperature coefficient of resistivity of copper of 0.00427 per cent per deg. cent.) the copper loss $= a W_0 \left(\dfrac{234 + \theta_0 + \theta}{234 + \theta_0}\right)$

$$\text{Then} \quad W = W_0 (1 - a) + a W_0 \left(\frac{234 + \theta_0 + \theta}{234 + \theta_0}\right)$$

$$= W_0 \left(\frac{234 + \theta_0 + a\,\theta}{234 + \theta_0}\right)$$

The temperature rise (say θ_x) for this loss at sea level will be

$$\theta_x = K W_0^n \left(\frac{234 + \theta_0 + a\,\theta}{234 + \theta_0}\right)^n$$

If taken to a high altitude the temperature rise, with this loss, will be increased ϕ_2 per cent *i. e.*,

$$\theta = \theta_x + \frac{\phi_2}{100}\,\theta_x = \theta_x \left(1 + \frac{\phi_2}{100}\right)$$

$$= K W_0^n \left(1 + \frac{\phi_2}{100}\right) \left[\frac{234 + \theta_0 + \theta\,a}{234 + \theta_0}\right]^n$$

Let θ_s = temperature rise at the lower altitude for the given load conditions.

$$\theta_s = K\, W_s^n$$

$$= K\, W_0^n \left(\frac{234 + \theta_0 + a\,\theta_s}{234 + \theta_0} \right)$$

then $$\frac{\theta}{\theta_s} = \left(1 + \frac{\phi_2}{100}\right) \left[\frac{234 + \theta_0 + a\,\theta}{234 + \theta_0 + a\,\theta_s} \right]^n$$

Which may be written in the form

$$\frac{\theta}{\theta_s} = \left(1 + \frac{\phi_2}{100}\right) \left[\frac{234 + \theta_0 + a\,\theta_s + a(\theta - \theta_s)}{234 + \theta_0 + a\,\theta_s} \right]^n$$

Putting $\left(1 + \frac{\phi_2}{100}\right) = B$

and $234 + \theta_0 + a\,\theta_s = D$

$$\frac{\theta}{\theta_s} = B \left[1 + \frac{a\,(\theta - \theta_s)}{D} \right]^n$$

Expanding by the binomial theorem

$$\frac{\theta}{\theta_s} = B \left[1 + n\, \frac{a\,(\theta - \theta_s)}{D} + \frac{n\,(n-1)}{2} \cdot \frac{a\,(\theta - \theta_s)^2}{D^2} + . \right.$$

The terms after the second may be neglected without any appreciable error, then

$$\frac{\theta}{\theta_s} = B \left[\frac{D - n\,a\,\theta_s}{D - B\,n\,a\,\theta_s} \right]$$

$$= B \left[\frac{1}{1 - \cfrac{\cfrac{\phi_2}{100}\, n\,a\,\theta_s}{D - n\,a\,\theta_s}} \right]$$

or with an error of less than 1 per cent

$$\frac{\theta}{\theta_s} = B\left[1 + \frac{\frac{\phi_2}{100}\, n\, a\, \theta_s}{D - n\, a\, \theta_s}\right]$$

which reduces to

$$\frac{\theta}{\theta_s} = \left(1 + \frac{\phi_2}{100}\right)\left[1 + \frac{\frac{\phi_2}{100}\, n\, a\, \theta_s}{234 + \theta_0 + a\,\theta_s\,(1-n)}\right] \quad \textbf{(15)}$$

While equation (**15**) may be used for calculating the temperature rise for any altitude, it can be greatly simplified (without introducing any large errors) by assuming definite values of θ_0, θ_s, and n. Even though these values vary considerably in practise the effect on the final results is small and the error introduced by using average values is permissible.

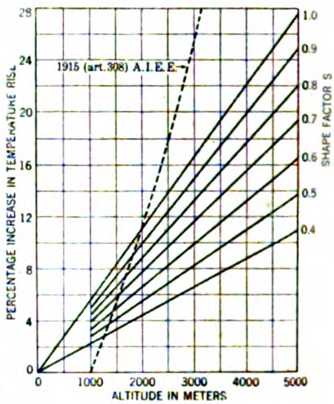


FIG. 7

Asumming a difference in altitude of 3000 m. (9840 ft.) or when $A = 3$ (in equation $\phi_2 = 5\ AS$) $S = 1$, $n = 0.8$, $\theta_0 = 30$ deg. cent. $\theta_s = 50$ deg. cent., and

$a = 0.0$, $\frac{\theta}{\theta_s} = 1.15$ or the new value of $\phi = 5.0\ AS$

$a = 0.5$, " $= 1.164$ " " " " " " $= 5.47\ AS$

$a = 1.0$, " $= 1.1753$ " " " " " " $= 5.85\ AS$

In other words, ϕ the percentage increase in temperature ranges from $5\ AS$ to $5.85\ AS$, depending on the ratio of copper loss to total (iron + copper) loss. Then we may put

$\phi = AS\,(5 + 0.85a)$ or with a maximum positive error of only 2.5 per cent when $a = 1$.

$$\phi = AS\,(5 + a) \quad \textbf{(16)}$$

Fig. 7 gives curves plotted from equation (**16**) where $a = 0.5$, and $e = 1$.

Table II shows a comparison between observed temperature rises and calculated temperature rises by equation (**16**) using the data shown in Tables III, IV and V giving complete data on observations conducted at Pittsfield, Boulder and at Leadville.

TABLE NO. II.

Test No.	Average surface rise deg. cent. at Pittsfield	Percentage temperature rise above tests at Pittsfield. Tests at Boulder: Predicted by equation (**16**)	Tests at Boulder: Observed above: Average room	Tests at Boulder: Observed above: Idle tank	Tests at Leadville: Predicted by equation (**16**)	Tests at Leadville: Observed above: Average room	Tests at Leadville: Observed above: Idle tank
			TANK NO. I.				
1	17.5	6.45	6.83	8.32	12.60	10.0	11.0
2	29.7	6.41	5.5	7.0	13.10	13.5	14.6
3	44.4	5.95	6.7	7.5	11.40	12.6	13.3
Mean values........		6.27	6.34	7.6	12.4	12.0	12.9
Mean value obtained by formula*....................					11.51		
			TANK NO. II.				
4	15.8	5.00	0	0	9.95	6.06	7.40
5	31.1	5.10	3.3	1.85	10.00	8.75	9.50
6	44.4	4.90	1.95	1.78	9.85	8.65	9.95
Mean values........		5.0	1.42	1.27	9.93	7.82	8.95
Mean value obtained by formula*....................					9.3		
			TANK NO. III.				
7	9.85	3.42	0	0	6.62	5.77	5.6
8	31.5	3.50	−3.34	− 3.34	6.92	3.82	4.05
9	48.3	3.35	−2.82	− 3.26	6.70	4.32	5.0
Mean values........		3.42	−2.08	− 2.2	6.74	4.6	4.88
Mean value obtained by formula*....................					6.12		

$^*\phi = 4.86\,A\left(\frac{W_c}{W_c + W_r}\right)$. NOTE: Instead of using here a constant value (S) for $\left(\frac{W_c}{W_c + W_r}\right)$ for different temperature rises, the values for W_c and W_r are based upon actual watts dissipated as given by equations (**1**) and (**10**) for surface temperature rises shown in second column above. Since the values for W_c and W_r change in opposite directions for change in altitude, the calculations are made for the proper values at an altitude of 1525 m. (5000 ft.) above sea level.

TABLE NO. III.

RECORD OF TESTS ON TANK NO. I. (CORRUGATIONS 22.8 CM. IN DEPTH.)

Test	Volts	Amperes	Watts[1] observed by		Temperature in deg. cent.					Observed barometric pressure in mm. Hg.	Calculated altitude in meters above		Humidity of air in % of saturation	Grains of moisture per litre of air	Date of test
							Average maximum oil[3]								
								Rise above							
			Volts × amp.	Watt-meter	Idle tank	Avg.[2] room	Actual	Idle tank tank	Avg. room		Sea-level	Pitts-field			
							PITTSFIELD								
1	110	14.35	1565	1564	30.3	30.0	51.1	20.8	21.1	730	360	0	21	0.106	3-27-15
2	110	26.6	2913	2907	30.4	30.1	64.7	34.3	34.6	735	300	0	16	0.086	3-26-15
3	110	43.1	4728	4707	32.4	32.0	82.9	50.5	50.9	727	395	0	17	0.95	3-23-15
							BOULDER								
1	110	14.5	1583	1538	36.0	36.0	58.5	22.5	22.5	615	1880	1520	21	0.132	5-14-15
2	110	26.7	2925	2908	37.3	37.4	74.0	36.5	36.7	620	1810	1510	18	0.130	5-12-15
3	110	43.5	4773	4688	37.2	37.2	91.5	54.3	54.3	621	1795	1400	20	0.140	5-10-15
							LEADVILLE								
1	110	14.35	1565	1564	20.9	20.8	53.0	23.2	23.1	523	3320	2960	25	0.122	7-24-15
2	110	26.4	2891	2897	30.0	30.0	69.3	39.3	39.3	519	3390	3090	20	0.099	7-23-15
3	110	43.1	4728	4727	30.9	30.9	88.2	57.3	57.3	537	3080	2685	22	0.106	7-22-15

(1) Less instrument losses.
(2) Average of 4 thermometers.
(3) Average of 3 thermometers.

TABLE NO. IV.

RECORD OF TESTS ON TANK NO. II. (CORRUGATIONS 8.9 CM. IN DEPTH.)

Test	Volts	Amperes	Watts[1] observed by		Temperature in deg. cent.					Observed barometric pressure in mm. Hg.	Calculated altitude in meters above		Humidity of air in % of saturation	Grains of moisture per litre of air	Date of test
			Volts × amp.	Watt-meter	Idle tank	Avg.[2] room	Average maximum oil[3]				Sea-level	Pittsfield			
							Actual	Rise above							
								Idle tank tank	Avg. room						
							PITTSFIELD								
4	110	14.25	1554	1547	30.5	30.1	54.9	24.4	24.8	727	395	0	16	0.081	3-19-15
5	110	28.4	3111	3117	32.3	32.0	74.3	42.0	42.3	728	382	0	14	0.081	3-18-15
6	110	41.0	4493	4507	32.4	32.0	88.7	56.3	56.7	723	443	0	14.5	0.078	3-16-15
							BOULDER								
4	110	14.25	1554	1556	31.5	31.1	55.9	24.4	24.8	616	1890	1495	34	0.176	5-20-15
5	110	28.8	3163	3117	36.4	35.5	79.2	42.8	43.7	613	1910	1528	29	0.188	5-18-15
6	110	41.5	4552	4573	38.8	38.3	96.1	57.3	57.8	613	1910	1467	22.5	0.162	5-17-15
							LEADVILLE								
4	110	14.1	1518	1547	30.2	30.0	56.4	26.2	26.4	520	3370	2975	21	0.110	7-27-15
5	110	28.4	3111	3117	31.8	32.0	78.0	46.2	46.0	519	3390	3008	24	0.130	7-26-15
6	110	41.3	4517	4517	31.7	32.0	93.6	61.9	61.6	519	3390	2947	24	0.116	7-25-15

(1) Less instrument losses.
(2) Average of four thermometers.
(3) Average of three thermometers.

TABLE NO. V.

RECORD OF TESTS ON TANK NO. III. (PLAIN)

Test	Volts	Amperes	Watts[1] observed by		Temperature in deg. cent.					Observed barometric pressure in mm. Hg.	Calculated altitude in meters above		Humidity of air in % of saturation	Grains of moisture per litre of air	Date of test
			Volts × amp.	Watt-meter	Idle tank	Avg.[2] room	Average maximum oil[3]				Sea-level	Pittsfield			
							Actual	Rise above							
								Idle tank tank	Avg. room						
							PITTSFIELD								
7	110	3.28	348	347	29.4	29.9	45.5	16.1	15.6	732	333	0	18	0.092	3- 2-15
8	110	9.78	1063	1066	30.1	30.2	72.1	42.0	41.9	743	201	0	17	0.092	3- 4-15
9	110	15.2	1658	1657	30.4	30.1	90.3	59.9	60.2	736	285	0	18	0.092	3- 6-15
							BOULDER								
7	110	3.23	354	342	33.6	33.6	49.0	15.4	15.4	616	1890	1557	40	0.240	5-25-15
8	110	9.87	1073	1067	33.9	33.9	74.4	40.5	40.5	613	1910	1609	24	0.148	5-23-15
9	110	15.6	1703	1637	33.7	33.2	91.7	58.0	58.5	619	1825	1540	32	0.190	5-22-15
							LEADVILLE								
7	110	3.26	346	313	29.5	30.0	46.5	17.0	16.5	519	3390	3057	18	0.105	7-29-15
8	110	3.78	1063	1066	29.8	30.0	73.5	43.7	43.5	519	3390	3189	19	0.113	7-28-15
9	110	15.2	1658	1667	30.0	30.1	92.9	62.9	62.8	520	3370	3085	19	0.105	7-27-15

(1) Less instrument losses.

(2) Average of four thermometers.

(3) Average of three thermometers.

An inspection of Table II shows that the calculated and observed temperature rises for all tests on tank No. I, which is the most important of the three, (because the effect is greatest) agree very well. Also there is only a slight difference, the observed being lower than the calculated values, for the Leadville tests on tanks No. II and III. Why the observed and calculated values for the Boulder tests on Tanks No. II and III do not agree any better is not clearly understood. This difference may be partly explained by the fact that different instruments were used at Boulder than at Pittsfield. A small error in watts would be expected to be more apparent for the smaller tanks where the loss is small. Another and probably better reason for this difference is that the room temperatures were from three to six degrees higher at Boulder than at Pittsfield, which as seen before, has the effect of increasing the tank's effectiveness for radiation. The difference is largest for the plain tank where radiation plays the more prominent part. Also the humidity of the air at the former place was somewhat higher, but in general this has been shown to have very little effect. (See Proc. A. I. E. E. Feb. 1913. Frank and Dwyer)

EXPERIMENTAL OBSERVATIONS

Observations were made under exactly the same conditions, with the above exceptions, at

Pittsfield, Mass.	approx.	305 m.	(1000 ft.)	above sea level
Boulder, Colo. *	"	1830 m.	(6000 ft.)	" " "
Leadville, Colo.	"	3360 m.	(11,000 ft.)	" " "

The writer witnessed the observations at Pittsfield and a part of them at Leadville. The housing (Fig 8) consisted of pressboard walls made up into sections so it could be easily assembled and disassembled. A view of the arrangements on the inside of the housing is shown in Fig. 4. The room temperature was controlled by means of sliding covers. In a few instances when the supplied loss was small, in order to keep the room temperature from falling below the chosen value, it was necessary to use a small electric heater.

Two 40.6-cm. (16-in.) desk fans were operated in a vertical

*It is desired here to acknowledge indebtedness to Prof. H. S. Evans, of the University of Colorado, who conducted the observation at Boulder at the expense of the University Eng. Dept. Also excellent work was done by Messrs. C. D. Fawcett and T. M. Victory in carrying on the observations at Boulder and at Leadville.

position in opposite corners of the room, with pressboard screens placed between the fans and the tank to prevent breezes from striking the surface of the tank. Tests made in this manner at different outside temperatures showed that under all conditions the difference in air temperature (approx. 90 cm. from tank surface) on level with the top and bottom of tank did not in any case exceed 2 deg. cent., whereas without the fans sometimes as much as 6 to 8 deg. cent. difference was observed. The room temperature used as a base was taken as the average of the four thermometers placed on a level with the center of the tank, in each corner of the room as shown in Fig. 4. In addition to the room temperature being used as the base, the temperature of a small lighting size transformer tank, filled with oil, set with its center on a level with the center of the tank under test, was also used. This was subjected less to quick changes in the outside air, than was the internal room temperature. The percentage of humidity of the air, during all tests, was determined by means of wet and dry mercury bulb thermometers. The barometric pressure was observed with a mercurial barometer.

Tanks. The dimensions of the three tanks used are given in Fig. 1.

It will be noted from the illustrations that the covers for the three tanks are insulated thermally from the tanks proper. Also for tank No. 1 the two plain sides were covered each with two thicknesses of 2.54-cm. (1-in.) hair felt, so as to increase the ratio between convection and radiation to a maximum. However, in order to determine the amount of heat passing out through these blanketed sides, the blanketing material was covered with a sheet iron casing of black color. By observing the temperature of this casing and also of the covers it was possible to determine the amount of heat lost by these insulated areas.

Tank No.	Run No.	Estimated loss by blanketed areas in percentage of of input loss
I	1	2.5
	2	2.2
	3	2.9
II	4	1.32
	5	0.75
	6	0.70
III	7	1.5
	8	1.8
	9	1.9

The foregoing tabulation gives the estimated loss by these blanketed areas in percentage of input loss on each tank for the tests conducted at Pittsfield.

We can therefore neglect these surfaces in giving the ratio of developed (effective for convection) to envelope (effective for radiation) surfaces. However, in making calculations of dissipated heat, these blanketed areas have been considered.

The developed surfaces effective for convection therefore were as follows:

TANK No. I.	(Corrug. 22.9 cm. in depth.)		
	24 corrugations	165,000 sq. cm.	(25,600 sq. in.)
	Space above corr. not blanketed	3,225 "	(500 ")
		168,225 "	(26,100 ")
TANK No. II.	(Corrug. 8.9 cm. in depth.)		
	47 corrugations	111,000 sq. cm.	(17,200 sq. in.)
	Plain bands at top and bottom	10,980 "	(1,700 ")
		121,980 "	(18,900 ")
TANK No. III.	(Plain sides)	24,200 "	(3,750 ")

The envelope surfaces effective for radiation were:

TANK No. I.	Corrugations	23,200 sq. cm.	(3,600 sq. in.)
TANK No. II.	Corrugations	35,100 "	(5,440 ")
	Plain bands at top and bottom	10,980 "	(1,700 ")
		46,080 "	(7,140 ")
TANK No. III.		24,200 sq. cm.	(3,750 sq. in.)

Method of Loading. Each tank was fitted with tubes wound (non-inductively) with resistance wires of zero temperature coefficient, and so arranged that by connecting in parallel various combinations proper losses were supplied, at 110 volts pressure, to give three maximum oil rises ranging from about 20 to 60 deg. cent. These tubes were so grouped that for each test the loss was uniformly distributed over the tank. By means of a diagrammatic record the same grouping was used at Pittsfield, at Boulder and at Leadville. The tubes were supplied at Pittsfield and at Boulder with current from an a-c. generator, and from an a-c. circuit of the Colorado Power Company at Leadville. The regulation was within one per cent under all conditions. In fact, at Leadville the regulation was considerably better than one per cent.

The instruments consisted of
One 150-volt voltmeter
One 5-ampere ammeter
One 600-watt, 15-ampere, 150-volt wattmeter
One 10:1 ratio current transformer.

The wattmeter was used to obtain a check on the input losses as found by the volt-ammeter method. (volts × amperes). The same instruments were used at both Pittsfield and Leadville. At Boulder the meters were furnished by the University of Colorado. All the thermometers were of the mercury bulb type and only those reading accurately within ½ deg. cent. by calibration were used. The four used for room read in ⅕ deg. divisions. The three used for the maximum (top) oil read in ½ deg. divisions.

In order to obtain the temperature gradient along the surface of the tanks (for checking input against dissipated losses), thermometers were placed at short intervals from top to bottom on both outside and inside bend of corrugations. Small felt pads and putty were placed over the bulbs to protect them from the influence of the room. At Pittsfield thermocouples were welded to the tank surface adjoining five of these thermometer bulbs to obtain a check on the temperatures. The thermocouples and thermometers read together, in almost all cases, within 1 deg. cent., showing that the felt pads were not causing hot spots from a blanketing effect.

For each test the run was continued at least 8 or 10 and in some cases 15 to 20 hours after conditions became constant, and an average of these readings (observed hourly) was taken as the final value.

CONCLUSIONS

The present A. I. E. E. recommendation (§308) reads as follows:

Altitude. Increased altitude has the effect of increasing the temperature rise of some types of machinery. In the absence of information in regard to the height above sea level at which the machine is intended to work in ordinary service, this height is assumed not to exceed 1000 meters (3300 ft.). For machinery operating at an altitude of 1000 meters or less, a test at any altitude less than 1000 meters is satisfactory, and no correction shall be applied to the observed temperatures. Machines intended for operation at higher altitudes shall be regarded as special. See Para. 267. It is recommended that when a machine is intended for service at altitudes above 1000 meters (3300 ft.) the permissible temperature rise at sea level, until more nearly accurate information is available, shall

be reduced by 1 per cent for each 100 meters (330 ft.) by which the altitude exceeds 1000 meters. Water-cooled oil transformers are exempt from this reduction.

COMPARISON OF A. I. E. E. RECOMMENDATIONS WITH $\phi = AS\ (5 + a)$

	Per cent increase in temperature rise above temperature rise at sea level.				
Altitude above sea level — Meters	1000	2000	3000	4000	5000
Altitude above sea level — Feet	3280	6560	9840	13,120	16,440
A. I. E. E. (§308)	0	11.1	25.0	42.8	66.8
Shape factor S	$\phi = 5.5\ AS$				
1.0	5.5	11.0	16.5	22.0	27.5
0.75	4.12	8.25	12.4	16.5	20.6
0.435	2 39	4.78	7.18	9.57	12.0

The above indicates that for equal iron and copper losses the present A. I. E. E. recommendations are for a difference of altitude of 3000 m. (9840 ft.), about 1.5 times too high for a surface with no radiation; about two times too high, for a surface dissipating 75 per cent of its loss by convection and 25 per cent by radiation (which ratio corresponds somewhat more nearly to surfaces of simple corrugations); and about 3.5 times too high for a plain surface ($S = 0.435$). For altitude differences greater than 3000 m. the error is larger, while for altitude differences less than 3000 m. the error is less.

Recommendations. It is recommended that for self-cooled (oil-immersed and natural draft) transformer, either the formula $\phi = AS\ (5 + a)$ or the one simplified and shown below be adopted and that no correction be made when $A = 1$ or less. If we assume that $e = 1$ and that the ratio of copper to iron loss is 3:2 respectively and divide the numerator and denominator of the expression for the shape factor through by "developed surface," we have

$$\phi = \frac{A\ (5 + 0.6)}{1 + 1.3\dfrac{\text{envelope surf.}}{\text{developed surf.}}}$$

or

$$\phi = \frac{5.6\ A}{1 + 1.3\ R} \tag{17}$$

where R = area of envelope cooling surface divided by area of developed cooling surface.

NOTE: In practice "R" varies from 1.0 (plain surface) to approximately 0.125 (complicated surface). For natural draft transformers dissipating all heat by convection $R = 0$.

Example. Let it be required to determine the temperature rise that a transformer in tank No. II (corrugations 8.9 cm. in depth) giving a 45 deg. cent. rise at sea level will attain when taken to an elevation of 3000 m. (9840 ft.).

We have $A = 3$

and
$$R = \frac{46080}{121980}$$
$$= 0.378$$

Then
$$\phi = \frac{5.6 \times 3}{1 + 1.3 \times 0.378}$$
$$= 12.8 \text{ per cent}$$

or temperature rise at 3000 m. above sea level will be 45 deg. $+ \left(\frac{12.8}{100}\right)$ 45 deg. = 50.7 deg. cent.

If it is desired to make correction in the opposite direction *i.e.*, one of reduction instead of one of addition, and if we let ϕ_r = percentage reduction in temperature rise at the high altitude

$$\phi_r = \frac{100\,\phi}{100 + \phi} \tag{18}$$
$$= 11.44 \text{ per cent or}$$

temperature rise at sea level will be, 50.7 deg. $- \left(\frac{11.44}{100}\right)$ 50.7 deg. = 45 deg. cent.

DISCUSSION ON "CALCULATION OF SUDDEN SHORT-CIRCUIT PHENOMENA OF ALTERNATORS," (DIAMANT), SAN FRANCISCO, CAL., SEPT. 17, 1915. (SEE PROCEEDINGS FOR SEPTEMBER, 1915.)

(Subject to final revision for the Transactions.)

F. D. Newbury: It is really surprising, as the author points out, how little thorough work has been done by American engineers on this subject. While Boucherot's paper was presented in 1911, in 1912 and even in 1913 the practise of engineers in this country was decidedly loose; for example, there was no distinction made between the maximum possible short-circuit current or the value of short-circuit current in the special case of a symmetrical wave. In my own experience, it was an open question in 1912, whether the important value was the maximum possible short-circuit current, occurring when the alternator was short-circuited at the zero point of the voltage wave, or whether the symmetrical wave was the one to consider in practical problems.

This leads to a reference made by the author to an article published by myself in April, 1914. It is elevating that article above its intended position to bring it before the Institute, because it was prepared to clear up some of these very elementary points in regard to short-circuit currents, and particularly to point out the difference in the actual short-circuit current value due to the time at which the alternator is short-circuited. At that time I was trying to point out a difference of 50 per cent between current values rather than a difference of less than 5 per cent that we are now concerned with.

In this connection I wish to correct an impression that may arise from this paper. I am in no way responsible for the empirical formula referred to in this paper. That was used in the organization with which I was connected at the time the article was written; I had no intention of presenting it as original, and as far as I know it was proposed either by A. B. Field, or by his assistant, J. A. Kuyser.

The author suggests that it is desirable to calculate the maximum possible short-circuit current from certain constants rather than by making short-circuit tests at full voltage. I think that is rather a dangerous doctrine. Certainly it is impracticable until engineers generally are convinced of the sufficiency of the method of calculation.

Until we are sure of this, the time is not ripe to abandon actual tests under operating conditions. Such tests are possible and are being made on even the largest two-pole and four-pole turbine alternators. Generators should be designed to withstand short circuits in service, and the only way to prove that they will withstand such severe service is to test them before installation. Incidentally, such tests are very apt to bring about improvements in coil bracing.

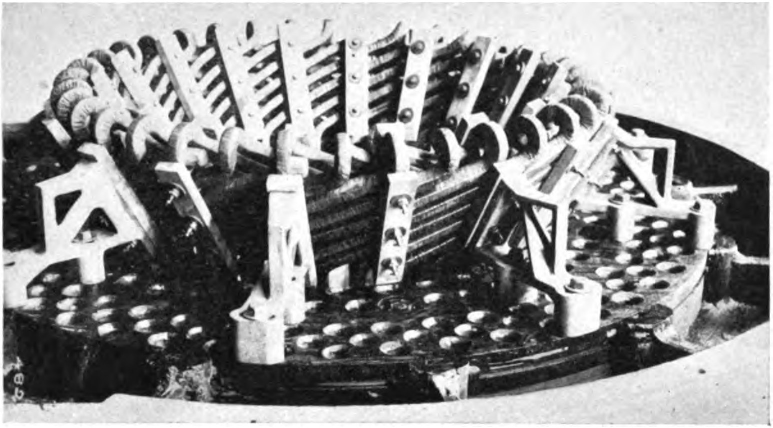
I agree with the author that the Institute should take up this question of the proper definition of instantaneous short-

circuit current. It is a proper matter for the consideration of the Standards Committee. It is only necessary to add to the words: "short-circuit current," "the maximum possible" short-circuit current; or, as the author suggests, it may be defined by stating that point on the voltage wave at which the short circuit occurs. However, I think the less technical definition given previously is preferable.

C. J. Fechheimer: The author has devoted considerable space to derivation of methods for predicting the rate of decay of current after a short circuit has occurred. We believe that it is well-nigh impossible to estimate with a reasonable degree of accuracy the constants which will affect the rate of dying down. Especially will this be true in those machines in connection with which instantaneous short-circuit phenomena are of greatest importance; namely, with large turbo-alternators of small number of poles; this being due chiefly to the difficulty of predicting the effect of eddy currents induced in the solid rotor, although the importance of other factors which make such calculation extremely difficult is not to be ignored. After all, we doubt whether an accurate estimate of the rate of decay of current is of such great importance. The destructive forces come as a result of the current rush at the first instant, and if our apparatus is properly protected to withstand these forces, the length of time that the forces endure, being always of short duration, is of minor importance. When a knowledge of this time is desired, it is generally sufficiently accurate to approximate the rate of decay from oscillograms taken on machines of somewhat similar magnetic circuit.

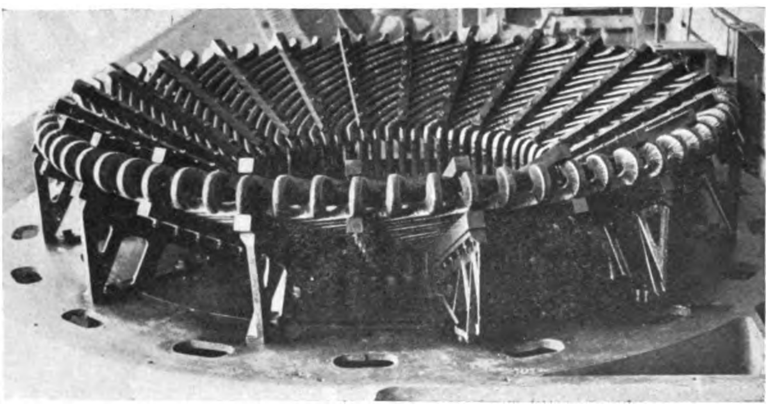
In order to predict the rush of current at the first instant, the two most important factors are—the point of e.m.f. wave, at which a short circuit occurs, and the reactance of the circuit. In so far as the point of wave is concerned, we should always be safe if we estimate the current rush as a maximum that which is obtainable on unsymmetrical short circuit. This may be taken to be roughly that given previously by Mr. Newbury as 1.8 times e.m.f. divided by reactance. We note that the author objects to the value of $(2 \times 0.9 =)$ 1.8, but we are inclined to favor so simple and reasonably accurate a rule. From a number of short-circuit tests on different machines, an approximate method for estimating the reactance is obtainable. As stated by the author and we wish to corroborate, the reactance of a three-phase star-connected alternator is substantially the same between terminals when a single-phase short circuit occurs as when all three phases are short circuited. This, then, eliminates some of the difficulties in estimating reactance which might arise from effects of mutual inductance. In working back from tests, to determine the value of reactance we would favor the method proposed by Mr. Field, and referred to by the author.

It is highly desirable to make alternators so as to withstand



[FECHHEIMER]

FIG. 1



[FECHHEIMER]

FIG. 2

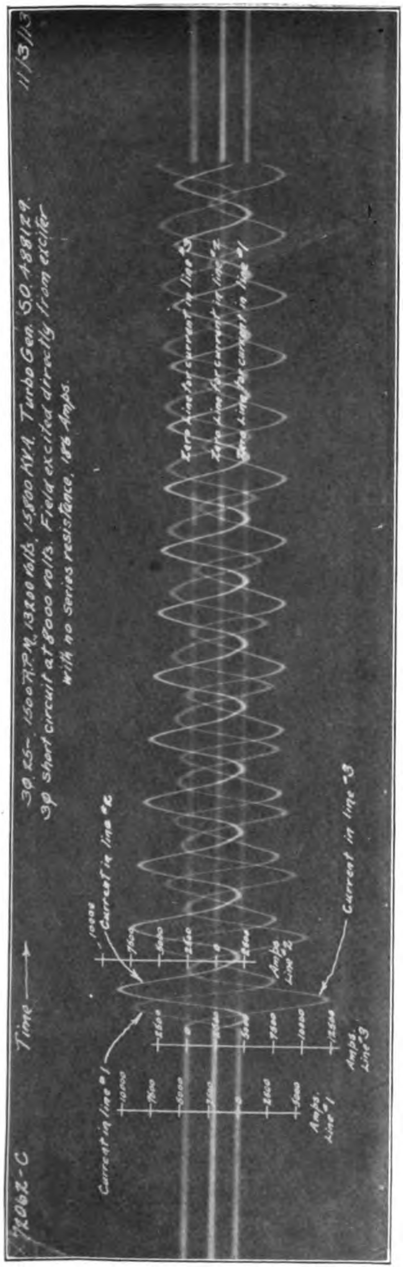


Fig. 3

[FECHHEIMER]

Fig. 4

[FECHHEIMER]

instantaneous short circuit. Especially in large turbo-alternators, is it important so to proportion them as to reduce to a minimum the magnitude of the current rush. This can be accomplished by the use of deep slots in the stator, thus allowing for considerable space between the top of the coil and top of the slot, thereby increasing the leakage flux linkages; and by using a large number of conductors in the stator; in other words, by designing the stator for large armature reaction. In order to prevent distortion of the end windings of the stator, they must be substantially braced. One method for securing the stator windings is shown in the accompanying photographs, Figs. 1 and 2. In the oscillograms Figs. 3 and 4 are shown three-phase short-circuit tests on a 15,000-kv-a., 11,000-volt turbo-alternator at full voltage. This machine had but two poles, and was built for 25-cycle operation. This short-circuit test was made with no external reactance in series.

It is interesting to note that in sustained short circuit, the field m.m.f. tends to produce a flux distribution which is substantially different from the opposing distribution, due to armature reaction. The resultant of these two m.m.fs. necessarily produces the flux that induces the e.m.f. which causes the current to flow. The e.m.f. in the individual conductor is quite different from a sine wave, but the current which flows has most of the harmonics suppressed. This is due to the two facts that, first, some of the harmonics are cancelled in the e.m.f. wave because of chording the windings, and because of distribution of the winding; and, second, because the high frequency of the harmonics prevents the flow of large current. In other words, the current and e.m.f. wave forms in the individual conductor are quite different. This condition must have some influence upon the magnitude of current on sustained short circuit. That is, the reactance which we would estimate from sustained short-circuit tests is to some extent fictitious. This in general does not apply on instantaneous short circuit.

It is interesting to note that when a short-circuit test is made on a large turbo-generator of the radial slot type of rotor, fire seems to encircle the rotor coil retaining rings for a brief period of time. After shut-down, no traces of the effects of this fire can be found. In all probability it is due to e.m.fs. which are induced by the rapid change of flux, such voltages tending to circulate current through the retaining rings, and the skin effect of the retaining rings tends to prevent the current from circulating.

We are inclined to question the advisability of inserting resistance to reduce the rush of current as recommended. A large amount of resistance would be needed, in order that its influence be felt, since the current is so far out of phase with the voltage. Furthermore, a useless waste would be occasioned by the employment of such resistance, and dif-

ficulty would be experienced in dissipating the heat incident to the losses arising therefrom.

We also question the advisability of the use of iron in the reactance coils (as suggested in the paper) if such are used in series with the generator. This iron fails at the critical time; namely, when the rush of current is the greatest, owing to the fact that the iron saturates. If so large an amount of iron be used as to avoid the saturation thereof, it would in general introduce a rather large reactive drop under normal conditions, and would increase the losses in the circuit. Furthermore, it is doubtful whether any material saving would be effected.

N. S. Diamant: In section VII, I have discussed in some detail the meaning of maximum possible current that an alternator will give when suddenly short circuited and I have indicated what seemed a good definition in the light of our present knowledge of the subject. I am very glad that Mr. Newbury went further, as I had hoped that someone would, and proposed that the Institute take up this matter and standardize the exact meaning of the terms maximum and maximum possible current than an alternator will give. I trust that the Standards Committee will not only consider this question but also the standardization of the term "sudden short circuits" in contradistinction to the "ordinary or "permanent short circuits" which may be called simply "short circuits."

I need not discuss here the advisability and necessity of the above standardizations and even the change of such superficial terms as "constants of an alternator" or "time constant" etc.

Mr. Newbury states that I seem to advocate or prefer the calculation of short-circuit current to actual tests. I may have failed to make myself clear on this point and therefore I take this occasion to say that I advocate not only actual tests but also calculation by means of the methods given and thus check results. Only, as I have indicated under section VII actual tests do not always solve the question of what is the maximum possible current in any given case so that certain amount of assumptions and calculations will be necessary in most cases and I believe that careful calculations should be made in such cases.

I think it would be bad and dangerous engineering practise to generalize from the comparatively few experiments given and assume that the methods of calculation described will give reliable results when applied to any and all types of alternators. I hope that the importance of the subject will induce many to test out the reliability and accuracy of these methods and when enough data are collected and the methods of calculation perfected and adapted to different types of machines then certainly calculations will be preferable to actual tests and will even be simplified into some such form as expression (**39**) takes:

$$I_{mp} = K \frac{\text{e.m.f.}}{\text{impedance}}$$

This is similar to Mr. Newbury's suggestion and the constant k which involves $\epsilon^{-\alpha_a \theta}$ and $\epsilon^{-\alpha_f \theta}$ may have a value of 1.75 or 1.8 or 1.85 etc., according to the type of machine.

Mr. Fechheimer's written contribution to the discussion was interesting but I do not think I was able to follow and understand all the points which he tried to bring out or criticize. At the outset he states that it is impossible to determine the attenuation factors as I have attempted to do. I take this to be a hyperbole to indicate the complicated nature of the subject. As I have briefly explained at the end of section I the different quantities involved in sudden short-circuit phenomena are very complex. So far, I am entirely in agreement with Mr. Fechheimer and this point should not be lost sight of in either reading the paper or expecting a reasonable accuracy in applying the different methods.

It seems to me that Mr. Fechheimer has failed to interpret correctly many parts of the paper and I think in reading it over carefully he will find explicit answers to his questions and criticisms.

Thus I am surprised to find that he has deemed it necessary to call attention to the inadvisability of reducing sudden short-circuit currents by means of resistance. I state clearly that reactance coils constitute the "economically and theoretically correct solution" of this problem. If Mr. Fechheimer examines the current equations he will see what I mean by the above statement.

As I have emphasized in the paper, I did not intend to consider the design of reactors but to show the beneficial effects of combining a small amount of resistance with reactance. Obviously in designing current limiting reactors, compromises have to be made some of which will depend on the special case under consideration and I simply desired to suggest that among many advantages and disadvantages that have to be considered the effects of resistance also should well be included. I regret that I did not have time to make any extended calculations and thus be able to make more definite statement in regard to this point; however, this would take me too far afield and it does not come within the scope of the paper.

Finally I am glad that Mr. Fechheimer's experience confirms the results of my experiments that short circuits *a* and *e*, Fig. 5, give practically the same rush of current. In this connection it is very desirable to have the experience of others as to the difference between single-phase short circuits with the neutral in and out as shown in Fig. 5, *b*, *c* and *d*.

DISCUSSION ON "THE REPULSION-START INDUCTION MOTOR" (HAMILTON), ST. LOUIS, MO., OCT. 19, 1915. (SEE PROCEEDINGS FOR OCTOBER, 1915).

(Subject to final revision for the Transactions.)

H. Weichsel: The design methods given by Mr. Hamilton can, according to my judgment, in some cases be shortened without interfering with the accuracy of the results. In some other cases it is possible to obtain somewhat more accurate results, without increasing noticeably the time required for the calculation.

The method given for calculating the winding constants is reliable and useful. The necessary time for computing these constants can, however, be quite materially decreased by the use of tables which give the winding constants or winding coefficients, as a function of the ratio $\frac{\text{number of slots wound}}{\text{total number of slots}}$.

Such tables have been calculated by me, and were published in the *Electrical Review and Western Electrician*, Oct. 15, 1910.

A tabulation is given in Mr. Hamilton's paper, showing the ampere-turns required for the different parts of the magnetic circuits. If I understand this table correctly, the necessary ampere-turns for the stator and rotor core have been calculated in the following manner. The distances *a* and *b* in Fig. 1 have been used as mean length for the magnetic path in rotor and stator core, respectively. Furthermore, the magnetic induction has been assumed as constant for all parts of the core, and is derived by the relation:

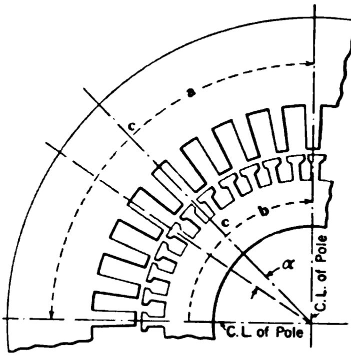


FIG. 1

$$\text{Induction} = \frac{\text{lines per pole}}{2 \times \text{core cross-section.}}$$

In reality the core induction is *not* constant but varies from point to point, and only half way between the pole centers at *c*, reaches the induction value found from the above relation. For all other points the induction is lower. A further investigation shows that the core induction varies approximately proportionally to the cosine of angle α. Magnetization curves can be made up, which consider the cosine change of the induction, and by aid of which it is possible to calculate the actual needed ampere-turns for the core. This method invariably gives much fewer turns for the cores, than the method used by Mr. Hamilton.

For calculating the no-load current, it is recommended to

multiply the magnetizing current, which occurs with rotor open-circuited, by the factor 1.95. This coefficient is, however, by no means a constant but it is influenced by the ohmic resistance and leakage reactance of the machine. In the A. I. E. E. TRANS., 1911, page 2125—I have shown how the influence of the ohmic resistance can be considered. In most cases, however, the influence of the ohmic resistance is not large in comparison with the influence of the leakage reactance. For this reason said co-efficient can be sufficiently accurately calculated by the formula $1 + \left(\frac{1}{1+T}\right)^2$ which considers the leakage reactance only. In this formula T represents the leakage co-efficient of the motor.

The circle diagram for a single-phase motor as shown in this paper, is in every respect identical with the well known circle diagram for a polyphase motor. I would like to call attention to the fact that in reality the following differences

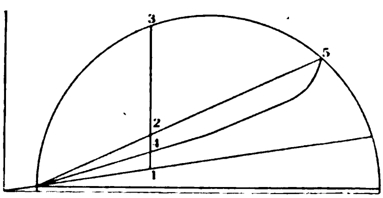


FIG. 2

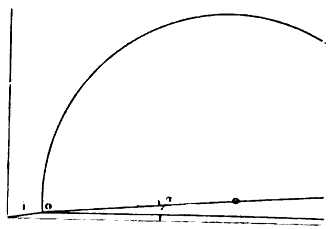


FIG. 3

between a single-phase and polyphase motor circle diagram (Fig. 2), exist:

In a polyphase motor diagram, the line 1-2 represents the rotor loss, and the line 1-3 rotor torque.

In a single-phase motor diagram, the line 1-2 also represents the rotor loss, but as the per cent slip of a single-phase motor is ***not*** the same as the per cent rotor copper loss, it follows that the line 1-3 cannot represent the rotor torque. The rotor torque is, however, represented by the line 3-4 where point 4 lies on a straight line half way between 1 and 2. This method of representing the torque of a single-phase motor, is correct up to approximately the maximum torque. Beyond this point the line 0-4 is no longer a straight line, but is curved and ends in point 5. The exact shape of this curved part is difficult to determine.

In using the circle diagram for deriving the performance of the motor from an idle and locked test, and from the ohmic resistance, I have found it most advisable to take the locked reading at about one half normal voltage. If this reading is taken at full voltage, the circle diagram quite frequently gives too

high a horse power output, due to the fact that the locked current frequently increases faster than the impressed voltage.

If the machine has relatively small ohmic stator resistance, the center of the circle lies on the base line of the diagram representing the constant losses. If, however, the motor has a relatively high ohmic resistance, then it is advisable to introduce a correction by drawing the line (0-1) under the angle

$$tg\alpha = \frac{i_0\, w}{e} \cdot \frac{2}{1 + 1.5\, T}$$

See Fig. 3.

i_0 = no-load current.

w = stator resistance. And the center of the circle should be located on this line.

T = single-phase leakage coefficient.

e = impressed voltage.

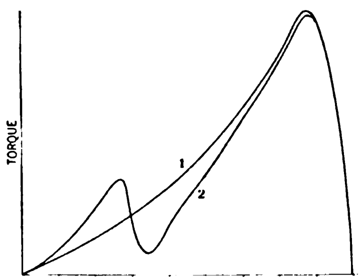


Fig. 4

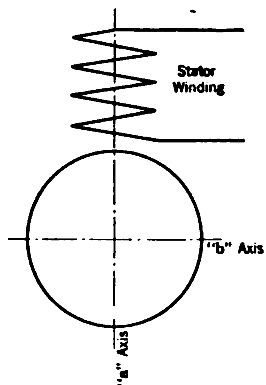


Fig. 5

We should not, however, deceive ourselves regarding the accuracy of any of these diagrams—especially is this true for the speed-torque curve derived from the circle diagram. The circle diagram is based on the assumption that the rotating field has a sine distribution in space. In reality, however, higher harmonics occur in the field shape and these harmonics distort the shape of the speed-torque curve. This statement is true for the single-phase motors as well as for the polyphase motors. Curve No. 1 in Fig. 4 shows a speed-torque curve such as derived from circle diagram, and refers to an ideal single-phase induction motor. Curve 2 gives the speed-torque curve for a single-phase induction motor where field possesses a third harmonic.

Reference is made in Mr. Hamilton's paper to the added iron losses. From the example given, it might seem as if the added iron losses are always high when the frequency due to the teeth is high. This, however, is not the case. It is quite

feasible that a machine with a very high tooth frequency has less added iron loss than another machine which has a very much lower frequency, due to tooth variation. This is due to the fact that the added losses do not depend only on the frequency due to the teeth but also depend, and to a large extent, on the amplitude of the flux variation caused by the teeth.

In calculating the rotor copper loss, apparently the loss due to the current flowing in the b axis (Fig. 5), has been considered only. In reality, however, a current pretty nearly equal in magnitude to the current flowing in axis b, also flows in axis a. The losses due to the current flowing in axis a and b, add to each other arithmetically, as I have shown in the *Electrical World.* (April 20 and 27, 1911.) The total loss in the rotor is therefore approximately equal to twice the loss in axis b.

A very quick method of determining the equivalent rotor resistance is given by Mr. Hamilton. He proposes an empirical coefficient K which lies between 1.4 and 1.7.

The coefficient K can, however, easily be calculated with great accuracy and very little time expenditure.

In the article already referred to on winding coefficients, a coefficient G has been plotted as function of percentage wound.

This coefficient G refers to equation: $i_2 = \dfrac{i_1 z_1}{z_2} \times G$

i_1 = stator current
i_2 = rotor current
z_1 = stator conductors
z_2 = rotor conductors

The coefficient K referred to by Mr. Hamilton, is determined by the relation: $K = G^2 \dfrac{l_2}{l_1}$

where l_2 = mean length of rotor conductor
l_1 = " " " stator "

If rotor has shortened throw, the coefficient K obtained by above equation, should be multiplied with the ratio:

$$\frac{\text{Full pitch winding throw}}{\text{Shortened pitch winding throw.}}$$

C. A. M. Weber: The square of the winding constant is used in calculating the reactance from the physical constants of the motor and hence it is important to determine this factor accurately. It is a well known fact that the secondary current corrects the field set up by the primary current to approximately a sinusoidal form and therefore a winding constant based on a sinusoidal flux distribution will give the best results. This constant may be calculated in a very simple manner as follows:

$$\frac{1}{2}\ \text{sine}\ \frac{180°}{2} = 0.5000$$

$$1\ \text{sine}\ \frac{150°}{2} = 0.9659$$

$$+1\ \text{sine}\ \frac{120°}{2} = 0.8660$$

$$1\ \text{sine}\ \frac{90°}{2} = 0.7070$$

$$1\ \text{sine}\ \frac{60°}{2} = 0.5000$$

$$\overline{4\tfrac{1}{2}} \qquad \overline{3.5389}$$

$$\text{Winding constant} = \frac{3.5389}{4.5}$$
$$= 0.786$$

Mr. Hamilton adds 37.5 per cent of the slot opening to the tooth face in order to take account of the increased gap due to slot openings. This may be satisfactory for one primary and secondary punching provided the same gap is always used, but will only lead to error as the depth of air gap is not taken into consideration.

In order to properly determine the effective air gap not only the width of slot opening but also the depth of mechanical air gap must be taken into consideration. It is obvious that if the air gap is increased the fringing will decrease and the effective gap will approach the mechanical gap and vice versa.

The author has calculated the main field magnetizing current but has assumed the cross field magnetizing current to be 95 per cent of the main field magnetizing current.

The cross field magnetizing current may be calculated in much the same manner as the main field magnetizing current by figuring the densities in the various elements due to the cross field. The data given by the author is not complete enough to start at the beginning of such a calculation. Therefore I will illustrate how the cross field magnetizing current may be calculated by using the main field current $i_m = 4.86$ as calculated by the author and assume 1.09 as the cross field saturation factor SF_c

The main field saturation factor, using the author's calculation of ampere-turns, is

$$SF_m = \frac{679.5}{609}$$
$$= 1.115$$

My experience shows that when the main field saturation factor is 1.115 the cross field saturation factor will be approximately 1.09.

Another element which enters into the determination of the magnetizing currents is the reactance X. The necessary physical data of the motor not being given, I will have to use the value of $X = 2.02$ ohms calculated from the test data given in the paper.

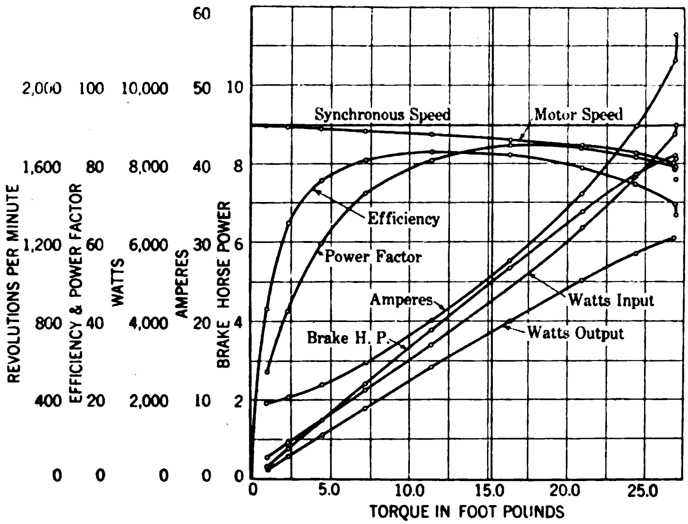


FIG. 6—REPULSION START INDUCTION MOTOR, 5 H.P., 104/208-VOLT, 60-CYCLE—4-POLE—1750 REV. PER MIN.

Then the cross field magnetizing current is

$$i_{ms} = i_m \times \frac{SF_c}{SF_m} \times \frac{1 - \dfrac{i_m X}{E}}{1 + \dfrac{i_m X}{E}}$$

$$= 4.37$$

The total magnetizing current is

$$i_0 = i_m + i_{ms}$$
$$= 9.23 \text{ amperes.}$$

which agrees more closely with the tested value of 9.25.

The iron loss which the author terms added iron loss is due primarily to the slot openings as stated but this loss need not be assumed as it can be calculated from the physical char-

acteristics of the motor and from a suitable curve plotted between density and watts per square inch.*

By referring to the table of calculations from locked rotor data it will be noted that the author has given the secondary resistance as the difference between the primary locked current squared divided into the locked watts and the primary resistance. This value of secondary resistance is not quite correct as it does not take account of the iron loss, the eddy current loss or the other factors which should be taken into consideration in a calculation of this kind.

Fig. 6 shows the performance of this motor calculated from the data which the author gives, according to the method outlined by Mr. W. J. Branson, in the TRANS. A. I. E. E., Volume 31, page 1749. It will be noted that this performance agrees very closely with the results obtained by the author from the brake test.

F. J. Bullivant: I would like to point out the importance to the user of the motor, of the discussion brought out by Mr. Hamilton with reference to brush setting. He points out that a better starting torque can be obtained by shifting the brushes away from the neutral, and a better pull-up torque can be obtained by shifting the brushes toward the neutral. When motors of this character are built for stock purposes they must necessarily be set for some average conditions of use, and if the user of the motor understands the proper conditions, as outlined in this discussion, he can help himself in any special cases of application.

Morgan Brooks: I would like to ask the author, if it is correct to have the length in inches of all parts of the magnetic circuit, except the air gap, the same. It seems there must be some error. It would be extraordinary to have the length of the different parts of the magnetic circuit all come out at 4.75.

J. L. Hamilton: Answering the last speaker first, 4.75 in. is the net length of iron and all sections of iron are figured as being the same. 5 in. is taken as the length of air gap parallel to the shaft so as to include the small air space between the different laminations of iron, as the reluctance of the air gap is practically no greater than if the face of the iron were solid. Another reason for figuring the area of the air gap in this way is that after the armature and field bore are turned or ground, the surfaces are practically solid or continuous when considered magnetically.

With regard to the points that Mr. Weichsel brought up; one was with regard to figuring the magnetizing current. The simplest way to calculate the magnetizing current is to consider the path of the flux which has the highest magnetic density or the magnetic path through the central field teeth of the pole and the total ampere-turns surrounding that mag-

*This method is described in a paper by Mr. J. E. Haussen, TRANS. A. I. E. E., Vol. XXVIII, page 997.

netic flux. It is apparent that if the magnetizing current is figured in this way, the correct value is obtained and it is useless to calculate the magnetic circuits through the field teeth which have lower magnetic densities at the instant considered. As the magnetic flux is figured when at its maximum, the magnetizing current is, of course, considered at its maximum and the effective value of magnetizing current is obtained by introducing the factor 0.707 which gives the effective value of the magnetizing current. This method gives correct results, as it has been used extensively in practise.

In regard to a simpler method of calculating the winding constant, that is a question for the individual, I would say. Personally, I have found this method simpler. Possibly someone else will find a method which will suit him better.

In regard to Mr. Weichsel's observations that possibly the secondary losses had not been correctly estimated, the secondary current at all times is measured from a point on the circle diagram midway between zero and the running free point, which is the correct point from which to measure the secondary current. If one wants to be more exact, which is not necessary however for commercial work, the point from which the secondary current is measured can be moved slightly toward zero in proportion, as the cross field flux is slightly lower than the main field flux. However, as the cross field flux decreases slightly as the motor is loaded this point from which the secondary current is measured should theoretically be changed for each load reading. These small refinements are not at all necessary and lead to but slightly increased accuracy.

This paper, I might add, in general shows a commercially practicable way in dealing with the motor and some of the different calculations may be questioned from a strictly scientific standpoint, but the author does not claim that the paper and the calculations are scientifically correct in each and every detail, but a method is outlined which can be followed very simply and will give reliable results.

One of the speakers brought out the fact that added iron loss was due to a number of conditions other than those mentioned by the writer. This is very true, and, for one, I would like to hear a discussion on the subject of added iron loss. As far as I know, this has not as yet been covered completely by any writer.

Discussion on "Single-Phase Squirrel-Cage Motor with Large Starting Torque and Phase Compensation" (Fynn), St. Louis, Mo., Oct. 19, 1915. (See Proceedings for October, 1915.)

(Subject to final revision for the Transactions.)

H. Weichsel. A few words in regard to the working characteristic of this machine, might be of interest. Mr. Fynn shows in his paper, a series of test curves. A study of these curves shows that this type of machine acts very much like a synchronous motor. With a certain compensation the power factor of the machine at no-load is leading. When the load increases, the power factor approaches unity, and with still further increase of load, the power factor goes slightly below unity. An over-excited synchronous motor shows exactly the same behavior.

By changing the magnitude of the compensating voltage, the power factor of the *BK* machine can be changed in exactly the same manner as this can be done in a synchronous motor by changing the d-c. excitation.

Increasing the compensating voltage of a *BK* motor, increases the power factor, but slightly decreases the efficiency. This also has its parallel in a synchronous motor which decreases its efficiency with increasing excitation.

The synchronous motor and *BK* motor are therefore as far as operating characteristics are concerned, fully identical with one exception that the *BK* motor does not run at synchronism.

The *BK* motor makes use of a commutator. A detailed study of this machine, shows, however, that its commutating properties must be superior to other a-c. commutator motors. Some of the most important reasons for this superiority are:

First; the commutator carries a comparatively light current, due to the fact that the greatest part of the working current is flowing in the squirrel-cage winding.

Second; due to the squirrel cage, it will be found that this machine is not very sensitive to higher harmonics in the line voltage.

Any other single-phase commutator motor I know of, shows quite noticeably, poorer commutation when connected to a line voltage which contains higher harmonics, than when operating from a line the voltage of which follows the sine law.

The commutation of the *BK* motor is hardly influenced by higher harmonics in the line voltage, on account of the squirrel cage, which has the tendency to cancel all the magnetic fields which the higher harmonics of the line voltage tend to produce.

Discussion on "Municipal Cooperation in Public Utility Management" (Kealy), St. Louis, Mo., Oct. 19, 1915. (See Proceedings for October, 1915).

(Subject to final revision for the Transactions.)

Charles A. Hobein: I think probably the chief cooperation of the municipalities in public utility management has been in the operation of electric railways. Particularly, the cities seem to have taken more of a part in the detail work of the railways rather than in the electric light or gas business. Of course, I am not speaking of the water systems which are largely municipally owned.

In connection with municipal cooperation in utility management there is a rather interesting situation which has developed in Los Angeles, where the City of Los Angeles has built a large aqueduct and there are several power sites along the aqueduct, one of which is being developed by the city. The city has taken occasion to say that it will either construct its own lines or buy out the distributing system of the Southern California Edison Company, which is one of the big companies supplying electric light and power in that locality—one of the three companies engaged in the business. Just how that situation is going to work out it is pretty hard to tell, but the California Railroad Commission is appraising the property of the Southern California Edison Company in the City of Los Angeles for the purpose of the city taking the property over by condemnation proceedings.

In talking to some of the men located in Los Angeles, who are connected with the public service corporations there, I understand the value which will probably be fixed will be much larger than the city authorities originally contemplated, for if the Southern California Edison Company should lose the load which it now has in Los Angeles, part of its hydro-electric plants throughout the state would be idle. There would be that loss of revenue, and the value of that portion of their plant which would be idle for a number of years has to be taken into account. There is a possibility in Los Angeles, in the final settlement, that the city ultimately will not purchase the property, but under some sort of contract arrangement might bill the consumers. The consumer owing the city for the power, and the city making out the bills and sending them to the consumers; and then have some other sort of an arrangement with the electric company for a division of the earnings; or some arrangement for municipal cooperation in the electric light and power business, which would more closely approximate some of the working relations now in force as far as the traction properties in other parts of the country are concerned. In Los Angeles there is a good deal of competition in the power business—three companies operating, but there is no competition as far as the rates are concerned, just a question of service. One of the competing

companies said it would rather have the city as a competitor than their present competitor, the Southern California Edison Company, the chief reason, of course, being that in a municipally operated plant the initiative is lacking.

M. G. Lloyd: I think it is very valuable to have a study of this kind made of the relations between the utilities and the city government. We have need of more cooperation than we have had. Often in the relations between the utilities and the government it has been a case of fighting rather than trying to cooperate.

It is advisable to have the methods of possible cooperation studied and put before us, and especially before engineers. They are the ones who ought to give more study to these questions, that in their nature are largely economic and political problems. If the thing is properly put before the city authorities and it is pointed out how the city and the utilities can work together, they will be more likely to see the way clear to make a really equitable adjustment.

I am very glad to see the point brought out, regarding the relation of real estate values to public utility development. That is a thing which is very often overlooked, and I think has had very little attention from engineers. It is undoubtedly true that the extension of the utilities service always results in an increase in the land values in the neighborhood affected. A computation regarding the New York municipal subway has shown that the values which are added to the lands adjacent to the subway, caused by the subway, are sufficient to pay the entire cost of the subway. Now, if these benefits were actually assessed upon the property directly benefited, if the people interested were compelled to pay for what they get, it would not be necessary to take municipal funds as is actually being done, to construct a utility of that kind. If that were done more generally, as was suggested, it would result in a much more rapid development of our utilities.

The question arises in that connection as to how justifiable is the statement made previously in regard to the extension of utility service, especially the railways, preventing the congestion and poor-housing conditions in the central parts of the city; that is to say, to what extent are the additional facilities created neutralized by the increased values given to the land, and the consequent increase in rents in the district to which their service is extended?

Mr. Kealy mentioned the Boston gas ordinance. It seems to me that the Boston idea is a very fair one to both the public and the utility. With the extension of state regulation there is probably going to be less settling of these questions in the franchise, and more of it will be done by the state commission. At the present time I think there are very few of the states whose regulatory laws permit adjustments of that kind, or at least which have specifically provided for them. In the Pen-

sylvania Utility Act and in that of Idaho, however, specific provision is made for that very thing—the commission is empowered to recognize in fixing rates the efficiency of management of the utility. That seems to be a very wise provision, and I think those of us who have any influence in framing the regulatory acts that may be passed in the future, in the states which have no such acts at present, should use our influence to have such provisions included in those utility laws.

L. B. Cherry: Regarding the assessing of abutting property to help pay the cost of extensions—is it not a fact that the extension benefits the whole town or the city to a greater or less extent. Why would it not be a good thing to arrange that the general tax list of the whole city shall pay a small percentage of the expense of extension and the adjoining property or the benefited zone the balance.

N. W. Storer: That is the rule on which the street pavement is handled, I believe—the abutting property must carry a portion of the cost and the city the balance.

Philip J. Kealy: Mr. Hobein has touched on the southern California situation, stating that a private company did not fear municipal competition nearly so much as it did that of the privately owned competition. This is a fallacy, for a municipally owned company can sell service at practically any price and make a seeming profit. The majority of the municipally owned lighting companies are selling their product below cost and the deficit in operating expense is frequently made up by bond issues. Of course, this results in a wonderful book profit. It is really surprising how many bond issues are voted for municipal electric light plants, out of the proceeds of which are paid at least a portion of the operating expenses.

As to the point made by Dr. Lloyd about congestion in some of the cities, perhaps the best illustration in this country is that of the city of Toronto, Ontario. Toronto has a very cheap street railway fare in one sense of the word. Eight tickets for a quarter are sold, good during the morning and evening rush hours, six tickets for a quarter during the balance of the day. School children's rates are ten tickets for a quarter six days a week and the cash fare is five cents. Toronto has developed very rapidly during the past twenty years and has perhaps the most intensified development of any city of North America, excepting only New York, *i.e.*, more inhabitants per acre. The reason is largely due to the fact that the traction ordinance under which the company operates provided that the service should be furnished at the rates just quoted within the city limits. This ordinance was passed and accepted by the company in 1891. After the annexation of certain territory to the city in about 1895 or 1896, a car line extension was petitioned for, which was refused by the company. Without going through a history of the litigation, the matter was eventually decided by the Privy Council of

England, which construed the ordinance provisions to mean that the company need give cheaper fares only within the city limits as of 1891. As a result, the fares just named apply at this time to approximately one-third of the area of Toronto, the balance of the territory being served by what are known as radial lines, upon which an additional fare is charged. It has been found that the great mass of the people will not reside in the double fare zone, thus explaining the great density of population in that comparatively young city.

Glasgow, Scotland, which operates a municipal system, has, like most continental cities, a zone system of fares and it has not been many years since that city spent many millions of dollars in an attempt to abolish what are generally recognized as the worst slum conditions in Europe.

It is also a striking coincidence that such of those United States cities as have reduced fares, for example, Milwaukee, Cleveland and Columbus, are those in which the density of population is comparatively large. There is found a small city trackage and necessarily a smaller investment is required to serve.

Mr. Cherry's question, as I understand it, is that the benefited area should be divided into two parts, the territory immediately adjacent to the extension and the balance of the city, and that the territory most immediately benefited should bear the major part of the cost and the city at large bear the other portion of the cost. I can see no difficulties as to the enactment of such a law or for a law enforcing such a theory. In fact, that is a theory on which most large public improvements are quite frequently carried out, the city through a bond issue bearing a portion of the expense, and the balance (generally the major part) being paid for by the benefit district in which the improvement is to be carried out.

L. B. Cherry: The added value would be taxes and would go into the city treasury and in that way benefit the city in addition to the whole population having an opportunity of getting additional transportation by that improved system of extended lines.

P. J. Kealy: That is undoubtedly the case. In Kansas City, when our new ordinance was under discussion the objection was made that it would curtail the city funds, since certain revenues paid to the city would no longer so continue. In rebuttal of such objection, it was proved that the building of some twenty-five miles of extensions required by the ordinance, would enhance property values and the additional amount of taxes which would be realized, because of the additional value so created, would practically offset the direct contribution formerly made by the traction company to the city treasury.

DISCUSSION ON "RECENT RESULTS OBTAINED FROM THE PRESERVATIVE TREATMENT OF TELEPHONE POLES" (RHODES AND HOSFORD), ST. LOUIS, MO., OCTOBER 19, 1915. (SEE PROCEEDINGS FOR OCTOBER 1915.)

(Subject to final revision for the Transactions.)

Herman von Schrenk: Mr. Hosford brought out the important factor about the changes which take place in poles after service and I note throughout the discussion, in the report and in the tables that the word decay is used. I judge from the description which Mr. Hosford gave us just now that the word decay as he used it, refers not so much to the impregnated portions of the pole as to the parts which lie beneath those portions. The experience which we have had in other structures, notably in railroad trestles, with piling, etc., has been entirely in accord with the observations he gives here. I only recently had occasion to condemn a railroad structure of creosoted piling, 180 feet long, after only four years of service, which showed marked decay, when, as a matter of fact those parts of the wood impregnated with the creosoted oil were perfectly sound; but, just as in the case of the poles described as being subjected to brush treatment, the fungus spores had penetrated through the season checks and brought about decay underneath. What I want to know is, did Mr. Hosford in an examination of these poles find any of that decay in the impregnated sections of the wood—this question refers particularly to the butt or full cell process—in which the creosote had penetrated?

The second point I would like to call particular attention to is the conclusion I reached after reading this paper, emphasizing, first of all the high efficiency of the poles which were treated so they received the maximum impregnation, and in the second place, a maximum retention of the preservative. I was very much impressed at the last inspection I made of the German government telegraph and telephone lines, where the maximum amount of creosote was injected. The percentage of failures was very, very low, where that proceeding had been followed. The difference between the brush-treated poles and the so-called tank or full cell treated poles, as shown by these records, is very striking; and I would like to have Mr. Hosford confirm the impression which I have obtained here, that judging by the results which they have secured so far, there is every indication that butt treated poles or full cell treated poles will give a very much higher probability of longer return on the investment than is the case with the brush treated pole.

The third point I would like to bring out—and I may perhaps be treading on dangerous ground in raising this point—is to ask Mr. Hosford whether there was any particular reason for initialing by letters the results of the so-called proprietary preservatives, in other words the trade-marked compounds. I would personally like to know what "*A*, *B* and *C*" stand for. The great trouble with these proprietary compounds is that they

come to us full of claims and with certificates from engineers all over the country, showing what beautiful results these substances give. Instead of charging ten or twelve cents a gallon for high grade coal tar, they want seventy-five or eighty cents a gallon. I should think it too bad, unless there is some particular reason to the contrary, if these particular pieces of research could not be made available to all who are interested, with a clear statement of the preservatives and what they stand for. We are confronted at the present time with an agitation in Congress on this particular subject. I doubt not that many of you have received circulars calling for a "Pure Food Timber Preservative Law" to be enacted by Congress. I have received copies of these circulars from engineers in various parts of the United States, including even to-day's mail, asking what action they should take. One of these circulars was sent to me as chairman of a committee of the American Society for Testing Materials, asking that that organization should take some action. While that is a good thing for a proprietary compound, there are obvious reasons why coal tar should not be subject to that particular kind of restriction, and I ask Mr. Hosford if we could get him to divulge what these symbols stand for.

The fourth point in my mind is, in making the chemical examination of the poles, was any attention given to the difference between the oil on the outside of the pole, near the ground line, and that further towards the middle of the pole? That is a very vital point in the discussions now going on in connection with specifications for treated poles.

I was particularly impressed with the statement that the poles with heavier outside evidence of treatment, as indicated by the hardened tar, had a greater tendency to resist decay, reinforcing the conclusion that life will increase with the amount of preservative applied. I would like to know whether all indications so far do not point in favor of a generally increasing tendency both among operations on telephone lines and in the railway practise, to try to treat the timber irrespective of the amount of oil used, in other words, to treat the timber with the amount of preservative it will actually hold, instead of with a given quantity per cubic foot. Of course we run into objections from the financial department, because we would probably treat the poles with more oil than they would pay for. Do not all the results shown here indicate that the better the treatment the better the probabilities of length of life to be obtained?

Clyde H. Teesdale: Mr. Rhodes and Mr. Hosford have shown that brush-treated chestnut and cedar poles will probably last from 5 to 6 years longer than the untreated poles. The cost of this treatment is very low. With coal-tar creosote it ought not to be over 30 cents for a 30-foot pole if a large number are treated at a time in one place. With an added life of 4 to 5 years, a cost as low as this offers a very good return. This is particularly true in the case of poles used by electric light and

power companies, who usually use larger poles than a telephone company. Where large poles are used a greatly increased first cost makes it possible to pay a considerable price for a preservative treatment, provided a good increase in life is obtained. The question of giving a thorough open-tank treatment to large poles is, therefore, worthy of serious consideration.

In Mr. Hosford's paper the brush treatment is dealt with to the greatest extent, and is the one with which the most definite results were obtained. It appears desirable, therefore, to discuss the limitations of this method of treatment. It has been found, for example, that brush-treated western yellow pine poles last practically no longer than similar untreated ones. Furthermore, it is obvious that woods which do not last well above the ground line will not be benefited by either a brush or open-tank treatment at the ground line. Therefore, such species as sap cypress and sap yellow pine, especially when set in the South, should be treated throughout the entire length of the pole, because the sap in such poles decays very readily, even above the ground line. I may say further that the brush treatment is not well adapted to timber which may be subjected to wear from abrasion. If railroad ties were given a treatment as superficial as the brush treatment of poles they would show almost no increase in life, because the portion penetrated with the preservative would be worn away very rapidly. Hence, one should bear in mind that, while brush and open-tank butt treatments give excellent results on telephone poles made from durable species of wood, these methods of treatment are not adapted to poles or timbers made from nondurable woods, nor are they adapted to those forms of timber subjected to wear, abrasion, etc.

One other point which I have in mind concerns the life of green versus air-seasoned poles. The paper under consideration brought out the point that untreated seasoned poles do not last any longer than those set green. This has been our experience with other forms of timber where accurate records have been kept. It is contrary to some of the older theories, but now that we have accurate records on many of these service tests we find that there is practically no advantage to be derived from seasoning, not only poles, but ties, fence posts, and other forms of timber. In fact, if the timber is held for an undue length of time it may deteriorate and a shorter length of life may be obtained.

C. A. Hobein, Jr.: I want to ask one question about the experience with cypress poles. I recently visited a railroad property in the state of Iowa. They used cypress poles and their experience has been very unfortunate. I inquired whether they had used the brush treatment, and it seemed they had used the brush treatment on the butts of these poles but they did not seem to feel it had done much good. The poles had been in the ground only a few years and they had practically all to be replaced.

L. B. Cherry: Has any one noticed any difference in the decay of the poles that carried reasonably high potential currents, due to the leakage of the insulators and grounding of the current through the moist wood?

N. W. Storer: Are the poles impregnated in vacuum? Perhaps Mr. Hosford can tell us a little about that.

L. B. Cherry: I desire to ask another question, in regard to the green poles and the dry poles. When the dry poles were impregnated were they thoroughly dried, or was the moisture that was natural in the wood, in the atmosphere, sufficient to affect the impregnation? It seems to me that the theory of the matter would be this—the reason a green pole should last longer than the treated poles which were dry when treated, was that the moisture which was already in the green pole, the sap, was in a way of the same material as the wood itself, while when it was dried and put in the ground, it would absorb the moisture from the earth and an electrolytic action would set up in the fibre of the wood.

R. F. Hosford: First, with reference to Dr. von Schrenk's question about where and how decay was found to occur. Taking all the experimental groups, the brush treated poles are those we have had the best opportunity to study. The typical form of change is the one which we have illustrated in the paper. This typical form has been found in practically every case where we could determine how decay began. The only exceptions are two or three cases that are mentioned on one of the pages relating to analyses. You will find there that we saw two or three poles where direct disintegration of the treated layer had occurred. That is rather rare, and we have gone far enough in getting decay started on brush treated poles to be safe in saying that is not a typical form of change.

We do not know so much about where and how open tank poles begin to decay.

Herman von Schrenk: In this Table VII referring to the Montgomery-New Orleans line you give the number of pieces in line decayed to the point of reconstruction, 75. Were those all brush treated?

R. F. Hosford: No. That table does not refer to brush treatment. That is a pressure treated line.

Herman von Schrenk: What is the significance of the word decay, as used in that connection?

R. F. Hosford: We are using the term decay, in the tables, as covering all types of disintegration whether the change actually occurred through insect attack or through the action of fungus growth. For simplicity in tabulation and to indicate how long the pole may be expected to last, we have taken the word decay and given it that meaning.

In a large number of cases with the pressure treated poles the decay has started in the untreated interior core. It is possible in a few cases, although we have not got enough evidence so

that we can be sure about it, that the gradual loss of preservative from the pole has occurred to such an extent that the amount of preservative remaining in the pole is so low that it perhaps cannot longer prevent the inauguration of decay.

Herman von Schrenk: Decay in the interior?

R. F. Hosford: No. Decay of the kind I have just been speaking of would begin on the exterior surface. You will notice, however, from the discussion of the causes of the beginning of decay in the two tables relating to pressure treated poles that the only important cause for the beginning of decay that we have been able to locate is referred to as checks or shakes. Checks or shakes would, of course, allow decay to start through exposing the untreated interior section of the pole.

With reference to the question concerning longer life for open tank and pressure treated poles, either of these two processes give a longer life than brush treatment. The experiments that we are describing cover essentially a scale of intensity of treatment. The results, as we expected when we began, vary with the intensity. Of course, the variations in the weather conditions, in the exposure, whether northern or southern, have also some influence upon length of life.

With reference to the names of the proprietary compounds given letter designations in the paper, I might say that the nomenclature in detail for all of these cases will be found in some of the publications referred to in the bibliography. We were not inclined to go into the matter of dealing with them by name in this paper because the conclusion we reach and follow in our practise is that dead oil of coal tar is better than these more expensive compounds. We point out that dead oil of tar has done as well as the proprietary compounds.

Relative to the analysis of the oils extracted from poles would say that I know of no case where we have segregated the treated part of a cross section from the untreated part and analyzed the two separately. As a matter of fact, the last analyses recorded in this paper were from samples taken as far back as 1909. We are in a position now to select a number of samples much more intelligently, which may enable us to elucidate some of the questions that are now open.

As to Dr. von Schrenk's last question with respect to heavy treatment versus light treatment, so far as I am aware, there is no current tendency towards treatment to refusal, which is the technical name for putting in as much as the timber will receive. What we are aiming to produce so far as our practise is concerned is to get our treatment, for example one of 12 lb. per cu. ft., more uniformly distributed through the pieces we have to treat, as indicated in the paper. A large number of pieces of any timber that is to be creosoted must be put in the cylinder at the same time. There are records in the case of certain studies which show that if no attention is paid to the selection of the pieces before treatment—say that they were all placed in the cylinder just as

they come—we would get widely varying results between different individual pieces when the lot is taken out. Our principal aim at present is to get the selected standard for the treatment realized in all the pieces or to get somewhere near to it. The indications are, from an examination of the poles treated by the pressure method 16 and 18 years ago, that we got treatments on certain individual pieces a long way out of balance with the average, and the paper has attempted to bring that fact out.

With reference to Mr. Teesdale's question and discussion I will say that we have attempted to emphasize the feature that he has also spoken about—the necessity of treating the upper parts of non-durable timber. We have endeavored in the paper to make this a means of distinction in the choice of methods to be employed in treating poles. Of course, it is true that the farther north you go the less obvious is the deterioration on the upper parts of poles. In the south, disregarding at least the sections of a pine pole which are heavily impregnated with rosin through "boxing" for turpentine, you will not find that any part of a pine pole will last very long, not even the heart of it.

I am glad that we drew from Mr. Teesdale the statement that the results obtained with poles with respect to the influence of seasoning is not unique and that it is true not only for poles but for other articles made from timber, that seasoning is not a very important means for increasing their life.

In answer to Mr. Hobein's question about cypress, the characteristics of cypress are about as follows: In the southern part of the territory in which cypress grows you can get varieties which are called in the trade, the red and the black cypress. The heart wood of these varieties is durable against decay. The sap wood decays rapidly, and decay of the sap wood has the further objection from the pole user's standpoint in that it occurs pretty evenly all the way up to the top of the pole. I have actually laid hands on cypress poles and found it possible to peel off a piece of decayed sap wood several feet long as you might take a piece of birch bark off a birch tree. There are varieties of cypress growing mainly in more northern latitudes known to the trade as the white and the yellow. Such information as we have indicates that not even the heart wood of these varieties is durable. I should say that most of our northern pole users would balk at using even the red or black varieties since the sap wood is not durable and breaks away from the pole in irregular fashion making the looks of the pole rather bad after it has been up for a little while. I have heard this objection as to the condition of the sap wood raised in connection with an experience with cypress in southern Michigan.

The better results obtained in wet locations are, I think, analogous to the common experience with all poles. Decay needs for starting, food,—which is in the pole—and air and moisture. If you immerse a pole in water or set it in swampy ground, which is pretty nearly equivalent to immersing it in

water, you exclude the air from the surfaces in contact with the soil. If you set a pole in a rock hole and use a few large pieces of rock to wedge it in place so that the pole surfaces are pretty thoroughly ventilated, the free access of air brings about a relatively rapid evaporation of water from the pole surface so that the moisture content is kept relatively low. In either of these cases, swampy ground or the open rock hole, the nearly complete exclusion of one of the elements needed for the life of the fungus substantially retards decay and thereby increases durability. However, neither of these two conditions for setting poles are encountered frequently in actual practise, so that their influence in increasing the life of poles is accidental.

With respect to Mr. Cherry's question about the effect of grounding, I would say that I do not believe that in the case of these poles the question of current comes into the matter at all.

The discussion of green and seasoned poles relates entirely to poles that are untreated, that is, it is not a question of green versus treated poles, but green versus seasoned poles, both of them untreated. A treated pole lasts much longer than either a green or a seasoned pole, even in the case of brush treatment, which gives the lowest increase in life.

With respect to Mr. Storer's question, I would say that the brush treatment is applied by hand with a brush. It simply depends on the absorptive qualities of the wood and the very slight pressure applied to its surface for the liquid to make its way into the timber. You take care to see that the pole is dry—it must be dry if you want to get any oil into the timber. If it has been wet by rain and has not been given an opportunity to dry off, you will not get much absorption. The open tank treatment operates by creating a vacuum in the cells of the timber through which the preservative is drawn in when the treating bath is allowed to cool. In the pressure treatment we use a vacuum on practically all of our work because we usually start with a pole that is green or only slightly seasoned. We first steam the piece thoroughly to get the effect of seasoning in the way of volatilizing, dissolving, and driving out the water and the sap. We then finish the work analogous to air seasoning, by applying a vacuum which dries out the timber. We subsequently apply the preservative oil under pressure to force it into the cells of the timber. The function of the vacuum is mainly to assist in completing the seasoning preparatory to the application of the preservtive. It is true that in some processes the vacuum is used to help in the impregnation, but this practise is not common.

Discussion on "The Engineering Experiment Station of the University of Illinois" (Paine), St. Louis, Mo., October 20, 1915. (See Proceedings for October, 1915).

(Subject to final revision for the Transactions.)

E. J. McCausland: Are they doing anything in the University of Illinois in the way of popularizing engineering work? What Professor Paine has presented to us is largely, and in fact altogether, along very definite, scientific, high class engineering. I understand at the University of Wisconsin, and I know at the Iowa State College, a good deal is being done along the lines of more popular work. Is there anything of that sort being done in the University of Illinois?

L. T. Robinson: I noticed one view which Prof. Paine presented on the screen, which seems to me is a remarkable advance along the right lines; that is, we used to have opportunity to view these college outfits, both for research and instruction. They had a remarkable collection of apparatus, mostly in very well prepared cases with glass doors, and one would judge by the looks of the apparatus, that it remained there permanently. It was the pride of the professors to lead people through the laboratory and show them the fine collection they had, and that seemed to be sufficient. I imagine they led the students up in the same way. Lately we have seen a great change, if I saw these pictures aright. This change that has taken place all over the country has even gone further here than it has in any other place. The switchboards, the steam and electricity supply, the pipes, and the systems of ventilation and supply, and all that sort of thing, seem to be very well carried out and that is what makes a real laboratory. If you can have but one thing, you certainly should have the business end of the apparatus, and the other arrangements and detail parts you can procure and put on at almost any time. If the layout is not so planned that you can use 60-cycles, or direct-current, or one thing and another; that is, if you have to go without them entirely, or if you have to spend several hours or several days to get something rigged up to supply these things, and then only have, perhaps, one-half kw., which is not enough to do anything with in reality; you have not much of an outfit. I am pleased to notice this carrying out of the plan for complete provision in this instance to such a marked degree, to give the thing a good, useful and practical turn by the well balanced use of all the elements that go to make up a complete laboratory.

John D. Ball: Mr. Robinson spoke about the utilization of the instruments. I would like to extend that one point further; that is, to the utilization of brain power. I think we will all admit that among college professors there are really some very bright men, capable of doing valuable work, but they have not a chance to do it, for the reason that they are teaching students, that is their primary business. We have the advanced students who do some research work, but they

are few and far between, because after the four-year course most of the students leave college and the undergraduates are worthless for this purpose. That leaves no way for the college professor to express himself except by means of trained students who have had experience, and the experiment stations seem to give an opportunity to do this work in this way.

A. C. Lanier: As a result of investigations carried on by the experiment station, much information of value, which may not find its way into published reports, is secured. I should like to know if the experiment station attempts to incorporate in its records material of this character, using it to satisfy some of the inquiries received by the station. Does the organization of the experiment station provide machinery for satisfying general inquiries from records of published and unpublished investigations carried on in its laboratories?

Ellery B. Paine: In reply to the inquiry regarding the attempts at engineering work in the University of Illinois, I would say that through the engineering experiment station, we are aiming to do one kind of extension work. We have not undertaken exactly what has been attempted at the University of Wisconsin, or at some of the other institutions. The unique feature, perhaps, of our engineering college work is this experiment station, which is conducted on lines different from the other engineering experiment stations which have been established since the one at the University of Illinois. It may be a question whether the university should do more in extension work, but it has seemed best to do work that is worth while in scientific research instead of spreading over a good many fields and trying to do a good many things. What energy we have for outside work has been directed along the line of experiment station investigations.

In regard to the spreading of the information and giving aid, I would say that through the bulletins, this information is spread widely. The mailing list has over 8000 regular addresses. The bulletins are prepared in editions of 10,000, or more, and in a few instances second editions have been prepared. In many cases inquiries may be best answered by sending a bulletin, directing attention to certain parts of it. In other cases information may be given by the department which has been conducting the research. Always when any information is available, which is of any use to anybody, it is given freely. It is not possible to make a special research for individual companies, but it might result, if there were many inquiries concerning certain points, in starting a research to yield the information desired. The experiment station is conducted to be of service as much as possible, and inquiries or suggestions are gladly received. The paper mentions the fact that in several instances committees have been appointed of outside engineers with the idea of getting the benefit of the valuable experience of practical men, in deciding along what lines the energies of the station could most wisely be directed.

Discussion on "The Effect of Displaced Magnetic Pulsations on the Hysteresis Loss of Sheet Steel" (Chubb and Spooner) and "The Unsymmetrical Hysteresis Loop" (Ball), St. Louis, Mo., October 20, 1915. (See Proceedings for October, 1915).

(*Subject to final revision for the Transactions.*)

M. G. Lloyd: One interesting thing about this work is the methods of measurement which have been used. It seems to me the methods used by the first authors, at least the principal method used, that involving the volt-second-meter which, I think, is what is usually called a flux meter, is applicable only to specimens with very large cross-sections, such as the cores of transformers or other large pieces of apparatus. I should think with a small specimen it would not be feasible to take such readings as are described. Measurements on an apparatus of that kind are always valuable with the object of applying the results to other similar apparatus. I always feel they are not of much value when getting the constants of the material, determining a physical law, or determining exponents, for the reason that there is a very non-uniform distribution of the flux. The flux-density varies considerably over the area of the material being tested, and that fact is likely to vitiate the results so far as determining the constant of the material is concerned. On that account I think it preferable to make use of test specimens for that particular purpose, as has been done in the other paper.

I am sorry that more results are not presented to us making use of the a-c. method with the wattmeter, as is done in the first few tests mentioned by Messrs. Chubb and Spooner. It seems to me this particular case is the one where that method is particularly suitable, since it involves the same range of flux-density, but varying the middle point of the range. The great bugbear to determining hysteresis losses by the a-c. method is the eddy currents, but in this particular case they will not give trouble, for the reason that the same range of flux means the same effective voltage and consequently the same eddy-current loss. I assume the use of a sine wave, and that would be really essential to get any results of value in this kind of a test. I feel that the a-c. method is particularly suited to this determination.

In regard to some of the details of the first paper, it does not seem to me that the sixth conclusion that the displacement factor is a function of the permeability, is very fully borne out by the experiments, because there are only a few data given as regards that relation. It did not seem to me that they are sufficient to justify the results stated in that connection. As in the case of the Steinmetz exponent, I do not think that there is any particular significance to be given to this exponent 1.9 for the coefficient of the flux-density in the formula. It is not entirely constant even in the experi-

ments which are given here, and there is no reason to suppose that it might not vary even more if the experiments were more extended.

Trygve D. Yensen: I should like to call attention to a point that is not very clearly brought out in the paper, although it can be figured out by combining a number of the curves. The hysteresis loop, as we ordinarily think of it, has a form as shown in Fig. 1. We have found in our experiments, however, and other investigators have found, that in-

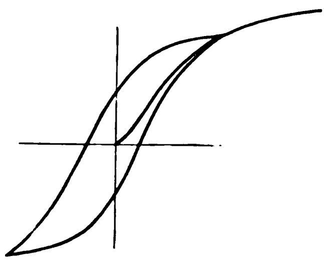


FIG. 1

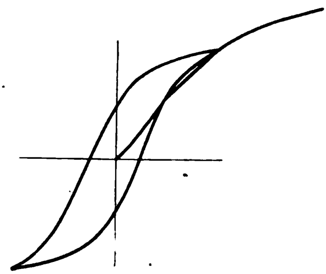


FIG. 2

stead of falling below the magnetization curve the lower boundary of the loop may cross the magnetization curve as shown in Fig. 2. An explanation of this feature would be very welcome.

Thomas Spooner: A comparison of Mr. Ball's results and data obtained by Mr. Chubb and myself may throw a little further light on the subject of hysteresis loss. As stated in our summary, we were unable to find any formula which would adequately express our data over all ranges, but, after reading Mr. Ball's paper, I took our data and attempted to apply it to his formula. Due to slight variations in testing, the results are not very satisfactory as calculated from the original data of Table I, so, in order to eliminate as far as possible, testing variations, I took the double log curves in Fig. 26 of our paper, and from those obtained the logarithms corresponding to each kilogauss of induction. I converted these to areas, subtracted the symmetrical loss areas from the displaced areas, converted these values to logarithms, just as Mr. Ball did, and plotted logarithmic curves between displacement and loss; that is, curves similar to those shown in Figs. 7 and 8 of Mr. Ball's paper. The slopes of these curves give the exponents corresponding to 1.9 in his formula

$$(h = (N + A\ B\ m^{1.9})\ B^{1.6}).$$

These exponents are as follows:

B	Exponent
1	2.35
2	2.10
3	1.93
4	1.76
5	1.61
6	1.49
7	1.45
8	1.18
9	109

The column marked *B* contains the pulsating induction values in kilogausses. The column marked exponent contains the exponents as figured by Mr. Ball's method.

Mr. Robinson pointed out that he could not exactly make the varying slopes of the curves of Fig. 26 coincide with a constant exponent of 1.9 as given by Mr. Ball. The reason is that, when calculated from our data, the exponent is not a constant, but decreases very considerably with the displacement. In fact, we can state with considerable assurance, that if we had been able to carry our displacements to somewhat higher values, the exponent would become actually negative; that is, the hysteresis loss would decrease with displacement. However, for calculating increased losses in the teeth of rotating machines Mr. Ball's formula is undoubtedly very satisfactory, because under those conditions, while the displacements vary greatly the amplitude of pulsating induction is small, which is the condition of his investigation.

In regard to the matter of closing the hysteresis loops, mentioned in Mr. Ball's paper, we found the same effect. In all cases, or nearly all cases the loops failed to close by less than 1 per cent of induction, and in most cases by very much less than that, so that we neglected the effect and closed the loops according to the first method suggested by Mr. Ball. As he points out, the errors due to this are very small.

Mr. Ball mentioned the fact that he excluded 2000 induction values from our data, because of certain discrepancies there. The only value which was to any considerable extent in error, was the second value of 1.18. That error was not noticed until after we had completed all our data. However, we know the reason for the discrepancy. Notice the diagram of connections for the volt-second-meter apparatus, Fig. 4. There was a safety gap there, which became short-circuited, increased the reading of the ammeter, and consequently, increased the apparent area of the loop. It may be interesting to state that the breakdown of this gap was produced by a discharge across a 50-cm. spark gap in the same room.

With regard to Dr. Lloyd's remarks, we have used the volt-second-meter apparatus on samples as small as the core of a

5-kw. distributing transformer and obtained very satisfactory results. I doubt if we could use a smaller sized sample than that. We chose this particular method, realizing that there are certain errors due to non-uniform distribution of flux in the transformer core, because we could obtain a large amount of data with a comparatively small expenditure of time and money.

The a-c. method, with all necessary corrections, is complicated. We have the eddy current losses, which can be taken care of, although it is difficult to determine the percentage when you work down to inductions of 1000. We prefer some methods of getting the hysteresis losses alone, if we can do that. In the a-c. tests which we made, we could not keep a sine wave voltage at the high inductions, due to unavoidable distortions, as pointed out in the paper, but we made corrections for form factor, which probably took care of that adequately. In regard to Table II of our paper, showing the relation between permeability and displacement factor, there is no apparent relation with an induction of 10,000 gausses. With 15,000 gausses, you will note the last two samples B and C have considerably lower permeability values at 15,000 and the displacement factors are decidedly larger. Now, the only possible error we could have made, that I could think of, is the distortion of the voltage due to the exciting current. This would tend to peak the voltage and produce an apparent displacement factor, which is smaller than the results we have obtained. We have made no form-factor corrections in obtaining these data. So, as a matter of fact, the displacement factors shown in the last two samples are undoubtedly larger than indicated by the table. The argument which led us to investigate this matter is this—suppose you have two magnetization curves as in Fig. 3, one for a high permeability sample and one for a low permeability sample, and suppose we have a displaced loop for each sample as shown, the pulsating induction and displacement being the same for each. It seemed reasonable to us, that the area of loop *a* for the low permeability sample should be larger than that of loop *b* for the high permeability sample. It may not be so, but what little data we did obtain, pointed definitely to that fact. At the lower inductions, the difference would be smaller, and would probably be masked by other effects.

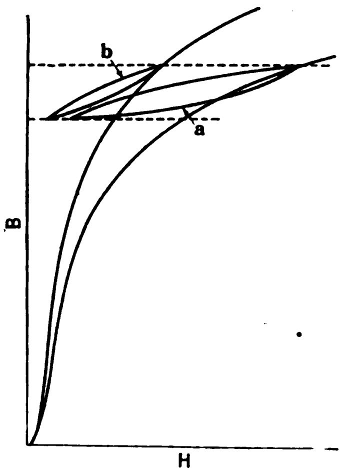


FIG. 3

John D. Ball: The agreement between the tests given in these papers and the exponent 1.9, Mr. Spooner has explained and it will not be necessary for me to bring it up again. I made these same calculations Mr. Spooner made, and I took the average of his results, without taking them individually, and find they are quite correctly represented by 1.9.

Speaking about the higher results of silicon steel, as mentioned in the paper, it is very unfortunate that for the two samples that I chose, the losses for the standard steel should be a little bit low and for the silicon steel they should be a little bit high. The silicon steel contains 2.5 per cent silicon, and is not transformer steel. That increased loss which has been mentioned has been observed a great many times, and is an increased loss at high inductions above what may be expected if deduced from the loss at *B* equals 10,000. I made an investigation of this, and can account for it. It is due to the fact that when the flux is going through the iron up to about *B* equals 10,000 the iron is carrying high flux density, and when you get above the *H* that gives *B* equals 10,000, the flux density of the scale increases extremely rapidly. The coefficient for scale is much greater than that for steel, and consequently you will get a much greater loss.

We accept the 1.6 law, and find it holds for steel, and also holds for scale, but when the proportion of flux is varying between the two, you would not any more expect the 1.6 or any other law to hold for the mixture than you would take the compressive strength of a brick, and expect it to hold for a brick wall with ten per cent of mortar. That is the way it seems to come out. I am inclined to think that the results of tests which show more losses for the silicon steel than for the standard steel are not at all truly representative of an average number of samples.

DISCUSSION ON " DECOMPOSING MAGNETIC FIELDS INTO THEIR HIGHER HARMONICS " (WEICHSEL), ST. LOUIS, MO., OCTOBER 20, 1915. (SEE PROCEEDINGS FOR OCTOBER, 1915.)

(Subject to final revision for the Transactions.)

George R. Dean: For some time I have been resolving magnetic fields into their higher harmonics, and wished for some convenient process. All this time I have been using the general procedure which involves a lot of integration, the combining of all kinds of hard integrals, I got my results all right, but now I am checking them up by Mr. Weichsel's method. Of course, these field waves as you call them, are to some extent a guess, their shape is not anything like as simple as one would think from the figures, but they come pretty close to being rectangles, trapezoidals, etc. One very interesting thing which I have been doing is to try to predetermine the harmonics in the current and field waves of alternators, transformers, motors, etc. And in order to get at the thing at all I have to decompose these magnetic fields.

To do that by the dry integration process is difficult. I can check up by Mr. Weichsel's process very nicely, because I can combine the triangular with the rectangular, trapezoidal, etc., whatever I need. The real magnetic field which, when cut by the conductor, produces the voltage in the armature, is the resultant of these three, and although your field produces a sine wave under no-load conditions, you will have a departure from the sine wave due to these fields. Of course these are not very large, but they are of considerable importance. They introduce the higher harmonics into the voltage and current waves. I have in mind starting out with a pair of differential equations, if I can ever get them set up right, and using these magnetic fields to predetermine the harmonics in the e. m. f. and current waves of the alternator.

It is obvious to me that higher mathematics are going to take a more and more prominent part in the high-tension work and in the design and predetermination of large apparatus. If it were not for the *B-H* curve we could get at something, but I believe in the case of the apparatus where there is an air gap, and most of the ampere-turns are used in the air gap, the permeability of the iron can be assumed to be large. Some take it at infinity, which it is not. We can, however, make an average correction for the iron and I hope get at something pretty definite in the predetermination of machines with air gap.

J. L. Hamilton: The thing that seems to me of principal interest in the building of induction motors in connection with the higher harmonics in the magnetic flux is the effect they have on iron losses.

If we have a 60-cycle induction motor with 48 slots in field and 60 slots in armature and wound four-pole, an oscillogram obtained from an exploring coil on the armature will give the following results.

At synchronous speed, 1800 rev. per min. or 30 rev. per sec.,

a complete cycle of the magnetic ripple in the armature takes place when the center of an armature tooth moves from the center of one field tooth to the center of the next field tooth. We therefore have in this case 48 field teeth multiplied by 30 rev. per sec. equals 1440 cycles per sec. of the magnetic ripple in the armature. This ripple or higher harmonic therefore has a frequency 24 times the supplied frequency of 60 cycles.

Considering the ripples in the field magnetism, it can be observed from an oscillogram record that a complete cycle has taken place when the armature has moved 1/60 of a revolution; 60 being the number of slots in the armature. 30 rev. per sec. multiplied by 60 ripples in the field per revolution gives 1800 ripples or cycles per sec. This is 30 times the primary frequency of 60 cycles.

The combination of field slots and armature slots directly affects the frequency of these ripples and also the amplitude. The shape of tooth tips, relative size of slot opening, etc., also affects the amplitude of the ripples. The combination of field slots and armature slots may be such as to get very high iron losses even with a relatively small number of slots in both field and armature as the amplitude may be great, even though the frequency of the ripples is comparatively low. Likewise the iron loss may be low with a comparatively large number of slots in field and armature if proportions of tooth tips, slot openings, etc., are correct.

It is the speaker's experience that these added iron losses vary quite widely and are often difficult to determine and locate.

If the writer of the paper just presented has any data on this subject showing more definitely why these losses should vary considerably and has any way of calculating same, I am sure designers in general would greatly appreciate such information.

N. S. Diamant: Starting with a triangular wave (isosceles) already analyzed into a Fourier's series, Mr. Weichsel shows *graphically* how a trapezoidal wave is equal to the sum of two triangular waves with a certain phase displacement. On the basis of this the equation of the trapezoidal wave is derived. Then the equation of the rectangle etc. is obtained.

Credit is due to the author for considerable persistent *mathematical* work in applying this method to a few special cases. When it comes to practical wave analysis, however, I cannot but entirely disagree with the author that his method will "facilitate analysis" and avoid "the usual long mathematical operations." Mr. Weichsel may have reasons for making these statements but the contents of the paper itself constitute strong evidence against him. Suppose we wish to analyze wave Fig. 1d. A hint is given in regard to the solution of the problem to the effect that the figure "obviously represents a composite wave which is the sum of a number of rectangular waves." There is very little about the problem that is obvious and even the number of the rectangular components is not stated.

In case of Fig. 1d, or any other, it is necessary first to deter-

mine graphically what and how many are the components of the wave under consideration and also what is their phase displacement: then *knowing* the " equation for each of the individual waves " it is necessary to " add values of equal order " and thus finally obtain an expression in Fourier's series for the wave. This, I am afraid, is too much of a roundabout method of attacking a practical problem. Standard works on electrical engineering[1] give coefficients for many common wave forms met in practise and even Mr. Weichsel will agree, I think, that for practical purposes it is most convenient to refer to such sources; or, ordinary methods of analyzing waves or simplified ones such as those due to S. P. Thompson and others can be used. These methods are all direct and *general* and much simpler than those given in the paper.

Were it not for the coefficients given in Figs. 6 and 7 the paper would have little *practical* value. For the benefit of those who may wish to make use of the table etc. it must be said that Mr. Weichsel fails to mention the fact that the coefficients given in paragraph on the triangular wave apply to isosceles triangular waves *i. e.* waves symmetrical with respect to the $\pi/2$ axis. This is not necessarily the case with all flux waves of commercial machines, especially under load conditions.

L. W. Chubb: (by letter): This paper on the harmonic analysis of magnetic fields shows a method of avoiding direct harmonic analysis for certain geometrical types of waves and treating the same by the separation into triangular waves, the equations of which are known.

The analysis of geometric field forms by the method of the paper will be found to be of advantage in few if any cases, as the complete analysis is seldom required, and the extraction of one or a few components can be made quicker by the mathematical, graphical, or mechanical methods.

The waves covered by the paper have sharp discontinuities and therefore their harmonic expressions are infinite series. Actual field forms do not exist with discontinuities and rectilinear sides because of fringing and saturation.

The author has used decimal coefficients for his component terms, derived the formula in a rather laborious way and expresses the results in a form in which it is difficult to substitute.

By Gregory's series we know that the expansion of unity is $\frac{4}{\pi}\left(1 + \frac{1}{3} + \frac{1}{5} + \frac{1}{7} \ldots\right)$ and it can readily be shown that the rectangular wave of Fig. 1-c is:

$$Y_R = \frac{4}{\pi}\left(\sin x + \frac{1}{3}\sin 3\,x + \frac{1}{5}\sin 5\,x + \frac{1}{7}\sin 7\,x \ldots \textit{ad inf.}\right) H_R \qquad (1)$$

1. Lecons d' Electrotechnique General, P. Janet, Vol. II, p. 117.

also the rectangular wave leading Fig. 1c by 90 deg. is

$$Y_R = \frac{4}{\pi}\left(\cos x - \frac{1}{3}\cos 3x + \frac{1}{5}\cos 5x - \frac{1}{7}\cos 7x \ldots\ldots\right) H_R \qquad (2)$$

The triangle of Fig. 1A is the integral of this last rectangular wave and can be obtained by integrating (2)

$$Y_\Delta = \frac{4}{\pi}\left(\sin x - \frac{1}{3^2}\sin 3x + \frac{1}{5^2}\sin 5x - \frac{1}{7^2}\sin 7x \ldots\ldots\right) H_R \qquad (3)$$

or in terms of H_Δ

$$Y_\Delta = \frac{8}{\pi^2}\left(\sin x - \frac{1}{3^2}\sin 3x + \frac{1}{5^2}\sin 5x - \frac{1}{7^2}\sin 7x \ldots\right) H_\Delta \qquad (4)$$

This triangular wave can be displaced any angle ϕ and its equation will be

$$Y_\Delta = \frac{8}{\pi^2}\left(\sin(x-\phi) - \frac{1}{3^2}\sin 3(x-\phi) + \frac{1}{5^2}\sin 5(x-\phi) \ldots\ldots\right) H_\Delta \qquad (5)$$

This when expanded gives the general equation of the triangle displaced any angle ϕ and of any height H_Δ.

The resultant of any two or more such triangles can be obtained by simply adding the coefficients of like terms.

As an example, two triangular waves at $+\phi$ and $-\phi$ add to make the trapezoidal wave the general equation of which is

$$Y_T = \frac{16}{\pi^2}\left(\cos\phi \sin x - \frac{\cos 3\phi}{3^2}\sin 3x + \frac{\cos 5\phi}{5^2}\sin 5x - \ldots\ldots\right) H_\Delta \qquad (6)$$

By similar reasoning the equation of the rectangular wave may be expressed in any phase position and the equation thus formed can be used to add to other rectangles, triangles or composite waves.

Two rectanglar waves added together give the interrupted rectangular wave, the general equation of which is

$$Y_{R_i} = \frac{8}{\pi}\left(\cos \Phi \sin x + \frac{\cos 3\phi}{3} \sin 3x + \frac{\cos 5\phi}{5} \sin 5x + \ldots\ldots\right) H_R \quad (7)$$

Or

$$Y_{R_i} = \frac{4}{\pi}\left(\cos \phi \sin x + \frac{\cos 3\phi}{3} \sin 3x + \frac{\cos 5\phi}{5} \sin 5x \ldots\ldots\ldots\right) H_{R_i} \quad (8)$$

This method of derivation has the advantage of simplicity of form, and the equations which are expressed in sine and cosine terms are generally applicable for any phase positions and number of different waves instead of being limited, as in the paper, to the resultant wave starting at $x = 0$.

The coefficients or constants B, in paragraph on triangular waves, are the simple terms $\frac{8}{\pi^2} \times \frac{1}{n^2}$.

They are correct in numerical value but the signs are wrong in many cases. The signs should be such that when B_n is substituted equation (**1**) will stand.

$$Y_\Delta = \frac{8}{\pi^2}\left(\sin x - \frac{1}{3^2} \sin 3x + \frac{1}{5^2} \sin 5x - \frac{1}{7^2} \sin 7x + \ldots\right) H_\Delta \quad (9)$$

In the derivation of coefficients of the reactangular wave the author finds $B_1' = 1.275$ which is $\frac{4}{\pi}$. The succeeding values are $\frac{4}{3\pi}$, $\frac{4}{5\pi}$, $\frac{4}{7\pi}$, etc.

The harmonic expression of these few geometric waves are of value in solving problems containing discontinuous waves, but we have found them of little advantage in the analysis of field forms and derivation of voltage therefrom.

Corrective currents, slots, local saturation, fringing, etc., require magnetic fields to be laid out more carefully than simply drawing the geometric form which agrees with the winding distribution. With the mechanical analyzer the more accurate field form can readily be analyzed, and the related voltage or related curve derived by formula.

H. Weichsel: The triangular, trapezoidal, etc., field shapes exist only when a machine has an infinite number of slots. The field shape of a machine with a finite number of slots has more the appearance of Fig. 1. The corners 1, 2, 3, etc., in the actual wave, will probably not be as pronounced as shown in this figure but will be more rounded.

In order to handle the subject in such a manner as to enable the designer to readily make use of the derived results, it was necessary to neglect refinements and to assume that the machine has an infinite number of slots. In this connection, it might be said, however, that the exact equation of a field such as

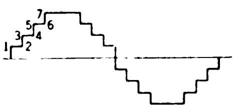


FIG. 1

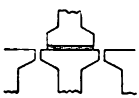


FIG. 2A

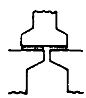


FIG. 2B

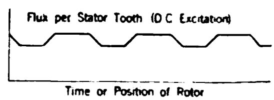


FIG. 3

given in Fig. 1, can be derived by assuming a number of rectangular waves superposed.

Mr. Hamilton referred to the additional iron losses. He touched a very important subject, which unfortunately, however, has not been sufficiently investigated. The higher harmonics which produce the largest amount of the additional iron loss, in induction motors for instance, are of a different nature than those harmonics discussed in my paper. These latter are simply produced by the phase belt distribution, assuming infinite number of slots. The higher harmonics, however, which are mainly responsible for the additional iron loss, are originated by the rapid movements of the rotor teeth against the stator teeth. Let us assume that the stator is excited by a direct current. As long as the air gap section in front of the stator tooth remains constant, a constant magnetic flux will flow from stator tooth to rotor.

As soon as the air gap changes, the flux passing from stator tooth to rotor must change also. A change in the air gap occurs, however, when the rotor tooth changes its position in respect to the stator tooth. It is evident that in Fig. 2A, larger flux will leave the stator tooth than in Fig. 2B. It is an easy matter to determine the flux which leaves the stator tooth for

different positions of the rotor teeth, by drawing the relative positions of stator and rotor teeth. Fig. 3 has been obtained by this manner and represents the flux of a stator tooth as function of the rotor position. But as the rotor is assumed as travelling at constant velocity, it also represents the flux as function of time. The additional iron losses, which are mainly eddy current losses, are evidently a function of rapidity of change of lines leaving the stator teeth.

Mr. Hamilton mentioned in his paper " The Repulsion Start Induction Motor," that the additional losses are sometimes 60 to 70 per cent of the calculated losses. I have seen machines where the losses were four times the calculated losses. In these machines the enormous losses were caused by faulty dimensioning of the stator and rotor teeth; the stator was of the open slot type. These figures might indicate the very great importance of the additional iron losses. It certainly would be of great help to designers if means could be found to predetermine said losses by fairly simple formulas.

Mr. N. S. Diamant seems to misunderstand the purpose of my paper. It was intended to show how magnetic fields which are produced by certain winding distributions, such as usually occur in induction motors, can be decomposed into their harmonics. For this reason the equations for rectangular and trapezoidal waves were derived. It was not intended, however, to use this method as a general wave analysis, for all kinds of waves. Mr. Diamant objects to the statement in regard to Fig. 1d that it "obviously represents a composite wave which is the sum of a number of rectangular waves." The wave consists of three different rectangular waves, two of which are "interrupted rectangular waves." The equations for any of these individual waves are "known" by referring to equation (7)

Mr. Chubb derived the equations for rectangular waves and trapezoidal waves by a strictly mathematical method and obtained the same results as given in my paper where the derivation was carried out by a method which I believe gives a better physical conception of the real conditions. It is certainly gratifying to see that both methods lead to the same results.

DISCUSSION ON "AUTOMATIC SWITCHBOARD TELEPHONE SYSTEM OF LOS ANGELES," (CAMPBELL), SAN FRANCISCO, CAL., SEPT. 17, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915.)

(*Subject to final revision for the Transactions.*)

Leo Keller: After I read Mr. Campbell's paper I decided it might be of general interest to say a little of the details of some of the cut-over work which was necessary, due to the fact that the original plant as laid out by the engineers was altogether knocked out by the tremendous growth and spread of the city of Los Angeles, growth in population and also in area. However, one feature of these changes, namely, the final cut-over, deserves a more detailed description, especially as the management of the Home Telephone & Telegraph Co. was very much opposed to any changing of subscribers' telephone numbers. This cut-over was, therefore, laid out with a view to letting each subscriber retain his old number and is more fully described below.

The manual equipment being the Kellogg Switchboard & Supply Company's two-wire multiple type, and the automatic being the three-wire type, made a "one stroke or slash" cut-over impractical, otherwise the matter of not changing telephone numbers would have been comparatively simple, such feats having previously been accomplished in a number of eastern cities.

This, therefore, had to be a gradual or phone by phone cut-over and we were confronted by the problem of calling manual telephones located in the Hill St. Exchange, and automatic telephones located in the Olive St. Exchange, both having the same prefix "A."

Mr. Campbell in previous papers has described the operation of an automatic system. It is therefore not necessary to do so here except to reiterate that in an automatic system the first digit or letter prefix of a telephone number, which in this case happens to be "A," indicates the exchange out of which such number is operated. Having, therefore, numbers with the prefix "A" working out of two exchanges during the cut-over, we had to find a means for connecting with the proper number whether same was working out of one or the other exchange.

It might be well to state that for the purpose of this cut-over it had been found practical to "half-tap", which means arrange the cables in such a manner that all subscribers' lines appeared in both the old and the new exchanges. The lines so "half-tapped" were carried by means of cables to their permanent place on the distributing frame, but held open from electrical contact with the new exchange equipment by small strips of fibre inserted between spring contacts on the distributing frame terminals. The usual procedure, which also was followed in this case, is to remove the fibre from between the spring contacts of the distributing frame terminal of the new

exchange and at the same instant insert a fibre strip between the corresponding spring contacts of the old distributing frame terminal. In this manner it will readily be seen a line can at will be cut loose from electrical contact with the old equipment and at the same instant connected with the new equipment.

It is also well to draw attention to the fact, that although the phones to be cut over were operating manually, still they were being called automatically from all automatic phones, which means that from all automatic exchanges in Los Angeles then in existence, trunk lines were run to the Hill street exchange, where after passing through convenient terminals, they finally terminated in incoming trunk selectors. These trunk selectors selected third selectors, which in turn selected connector switches all located in the Hill street exchange.

The installation of the new automatic switchboard in the Olive street exchange aside from the individual subscribers' line equipment, of course duplicated all the incoming "A" trunk selectors, third selectors and connectors in the Olive street building. Preparatory to the cut-over, these were all permanently installed and no temporary work had to be done except that from the third selector banks two sets of trunk cables were run, one permanent set to the new Olive exchange connectors, and one temporary set, which connected through a temporary set of impulse repeaters and underground trunk cable, through convenient terminals to the old connector switches in the Hill street exchange. Strips of fibre were inserted between the contacts of these terminals to keep them electrically open until time for the final cut-over.

The incoming trunk selectors in the new Olive exchange were connected by means of underground cables to the same incoming trunks terminating in the Hill street exchange (half tapped) so that an incoming "A" trunk line really terminated in both exchanges. Until ready for the cut-over they were kept from making electrical contact with the Olive exchange incoming trunk selectors by being carried through spring contact terminals, separated by fibre strips similar to those used on the connector switches in the Hill street exchange.

The old incoming trunk selectors in Hill street exchange were also carried through similar spring terminals. These, however, made contact but were ready to be separated by means of fibre strips at a moments notice when the proper time arrived.

After all of this had been duly installed and carefully tested, we were ready to divert the stream of telephone calls from its usual course over the new course, being the newly installed incoming trunk and third selectors in the Olive street exchange and from there into both the old connector switches of the Hill street exchange and the new connectors in the Olive street exchange.

This final cut-over was accomplished one Saturday night by simply removing all fibre strips from the connector terminals in the Hill street exchange as well as removing the fibre strips from the incoming trunk terminals in the Olive street exchange and at the same time inserting fibre strips in the incoming trunk terminals of the Hill street exchange. After this was accomplished the incoming trunk selectors in the Hill street exchange being now separated from the line would no longer operate. This in turn would automatically kill all Hill street third selectors, but instead the incoming trunk selectors located in the Olive street exchange being now electrically connected to the trunk lines would respond to the impulses and they in turn would connect with the third selectors in the Olive exchange. These third selectors in turn would not only select connector switches in the new Olive exchange, but would also select corresponding connector switches in the old Hill street exchange. In other words, a subscriber anywhere in the city in calling a number with the prefix "A" would as usual step up a first selector in his own exchange which would then select an idle incoming trunk selector in the new Olive street exchange, which in turn would select a third selector in the Olive street exchange which in turn would select two connector switches, one in the Olive street exchange and the other one in the Hill street exchange. Both connector switches would respond to the last two moves of the dial and would step up and rotate in perfect synchronism, so that, for instance, if the number called were A-2345 both the old and new connector switch would stop on contact "45" of the A-23 group. Now, as long as A-2345 still worked out of the Hill street exchange, the Hill street connector would signal and connect with it, while the Olive street connector would land on an open contact, while after A-2345 had been cut over to the new exchange the conditions would be reversed and the Olive street connector switch would ring the line while the Hill street connector switch would land on a blank.

After all of this was accomplished it only remained necessary to change the subscribers' station equipment from a manual to an automatic instrument, and to cut-over each line as above described by separating the line contact in the old exchange and by completing the corresponding contact in the new exchange.

In this manner we succeeded in transferring several thousand telephones from one building to another and from a manual system to automatic without changing a single telephone number and without interrupting the service for one minute.

Fred L. Baer (by letter): One point of special interest that Mr. Campbell could most likely have dwelt upon at greater length is the question of depreciation as exemplified in the Los Angeles installation. I was quite familiar with the early work done in Los Angeles by the Automatic Electric Company,

and within the past year I had occasion to go through Los Angeles and I visited the office in which the initial equipment was installed, and was impressed by the fact that after ten years of heavy service the original equipment was still in excellent condition and available for many more years of service. While it is true there have been many changes in the art in the past ten years, still it was possible to apply many of these changes to the original system as installed in Los Angeles. The service rendered by the automatic equipment is still of the high order which made the service so popular in the early days. A significant point is that the parts subject to wear can readily be replaced and the equipment kept up to its initial service standard, whereas the service rendered by a manual switchboard begins to fall off in quality as soon as the switchboard is a few years old, due to wear of parts that cannot easily be replaced.

The Los Angeles installation shows us that the depreciation of the automatic equipment due to wear is small, and that the depreciation due to obsolescence is trivial so long as the high grade of service can be maintained at a reasonable operating cost.

In the paper just delivered, Mr. Campbell has dealt with the case of the rapid growth of a telephone network, simultaneously with the unprecedented growth of the city. The initial exchange was equipped with manual apparatus, the rapid growth was taken care of by the installation of automatic equipment in other offices in various sections of the city with the subsequent cut-over of the one manual exchange so that at present there is a highly developed automatic network.

The progress made in this and other countries in automatic telephony during the last ten or fifteen years has removed many doubts from the minds of skeptics. There is no further questioning "Will it work?" "Will it pay?" "Will the public stand for it?" "Does the public want it?" Experience has answered these questions in the affirmative. The question of the day is, "What procedure is necessary for its adoption?"

Little argument is required to show the tendency in the art, that automatic operation of telephone plants will become universal in a not far distant future, not only in multi-office networks where the advantages are undisputed, but also in single office exchanges. This then being established, it will be feasible also to use automatic equipment, in part at least, for small exchanges in order to derive the benefits that are incident to automatic long distance dialing made possible by recent developments along this line.

There are many large cities both at home and abroad with multi-office networks that must ultimately adopt automatic service and the problem confronting the telephone engineers is the procedure during the transition period. Some favor the conversion of the central office equipment to automatic

but still retain the operator to set up the desired connection, in this case retaining the ordinary subscriber station equipment. These are the semi-automatic advocates. Others favor the preceding as an expedient during the transition period with the ultimate adoption of full automatic. These are the ultra-conservative automatic advocates. Still others favor the complete installation of automatic central office and subscriber station equipment and cutting into service one or more offices at a time so that the advantages of automatic operation immediately accrue. The latter might be called the ardent automatic advocates. Being of this latter class I might explain to some extent the plan followed in re-habilitating the multi-office network in Australia. Automatic operation of the telephone properties is in progress by the Australian government for all of the larger cities, having already been adopted in the cities of Geelong, Perth, Melbourne and Sydney. The work having progressed further in Sydney than in the other cities and the problems encountered there being typical, my further remarks will deal with this network. The metropolitan area of Sydney has a population of three quarters of a million within a radius of about twelve miles of the city proper. There are twenty-nine telephone offices in this area with about 32,000 telephones and other offices are contemplated. At the present time the two larger offices are served with common battery manual switchboards, three with automatic equipment and the remainder with magneto manual switchboards. The installation is now nearly completed of eight more automatic offices to replace present magneto offices.

Due to the fact that much of the wire plant associated with the magneto offices must be re-habilitated before it can be used in connection with central energy equipment the progress of the conversion is slow on account of the cost and the immense amount of work involved.

The full automatic network as planned will consist of ten district exchanges, all interconnected. These district main offices will in most cases have one or more tributary sub-exchanges. The sub exchanges will have trunks only to their respective district main exchange. By means of a switching repeater it is arranged that in making local calls in any sub-exchange a trunk pair will be used to the district main exchange for routing purposes, after which the trunk pair will be cut out of the transmission loop. Later on when these sub-exchanges increase in size, and the percentage of local calling increases, it can be arranged not only to cut the trunk pair out of the transmission loop but also to make the pair available to other calls.

The numbering scheme for the initial equipment with all automatic exchanges provides for five digit numbers throughout. Later, in some offices, six digit numbers will be required when additional equipment is installed; this will not, however,

interfere with the initial five digit numbers. After extensive tests the Post Office engineers decided in favor of a letter prefix and four digits for the telephone numbers, a prefix being allotted to each district main with its sub exchanges. The change in existing manual numbers is made by adding the proper letter prefix and increasing the present numbers by 1000 in the case of the district main exchanges and 5, 6, 7 or 8,000 as required for the sub exchanges. During the transition period, while a mixed system is being operated, call letters corresponding to the prefix for the district main exchanges are used by automatic subscribers to connect with the various manual traffic centers.

Calls from manual to automatic are made by way of existing manual trunks to the city "B" operator and from the city "B" operator to an operator at a special switchboard. These special switchboards are all located at one point for the present on account of the comparatively light load and the scarcity of trunks between outlying manual exchanges and the automatic exchanges now installed. The city "A" operators have direct access to the special operators. The operation is as follows: The city "A" or "B" operator goes on a non-busy order wire to the special operator and gives the number which the special operator records on her push button keyboard, simultaneously repeating the same to the ordering operator, after which she assigns the trunk. When the ordering operator takes up the assignment, a guard lamp lights, which indicates that the assignment has been taken; then the special operator depresses the start key of the motor-driven sending machine which sends out the required impulses for operating the switches in the distant automatic exchange. The city "A" or "B" operator, as the case may be, will receive answering supervision when the automatic subscriber answers. They will also receive disconnect supervision, and when the connection is taken down the automatic switches are released.

It is arranged that the special operator also has disconnect supervision, so that in cases of slow disconnection on the part of the manual operator she can release the automatic end of the connection, in which case she would advise the monitor of the slow disconnection.

The special desks are intended for use only during the transition period and will not be required in the full automatic network.

As indicated previously, calls from automatic to manual are made by the automatic subscriber calling a predetermined call letter to connect with the proper traffic center where he gives the number to an answering operator. The operator either completes the call by plugging into a multiple or transfers it over a manual trunk to a "B" operator in the required exchange where it is completed. When the automatic subscriber hangs up, the automatic switches are released, but the trunk line is held guarded until the manual operator who has double lamp supervision, takes down the connection.

Calls from one automatic exchange to another automatic exchange are, of course, full automatic in accordance with the regular practise.

In order that the maximum advantages would accrue to automatic subscribers, it had been suggested that in all the existing manual offices the growth be taken care of by means of automatic equipment and that a multiple of all the manual lines in the offices be made available to automatic switches. In this way then any subscriber having an automatic telephone could connect with any subscriber in the network, whether automatic or manual, without the intervention of an operator.

The service rendered with this mixed system is entirely satisfactory and a decided improvement over that given with the former manual system. As more and more exchanges are cut-over to automatic, the service will improve until with the full automatic they will have obtained the high standard of service rendered only by an automatic system, always uniform and dependable and free from the human vagaries and frailties that characterize manual service.

John Wicks (by letter): The automatic telephone system of Los Angeles, as described by Mr. Campbell, is a practical answer to the objections that were made a few years ago against the automatic telephone. At the time when the first automatic switchboard was installed in Los Angeles it was common to hear such remarks as that it might do for small isolated plants, but that the complexity of service required in a large city would demand so much manual assistance to the automatic switchboard as to make it impractical. The engineers of the Home Telephone Company of Los Angeles must have to some extent shared this view, for as noted in Mr. Campbell's paper, manually operated switching sections were at first installed in conjunction with every automatic board for interconnection with the manual switchboard. It is interesting, however, to note that with the growth of the city and consequent growth of the demands upon the telephone system, there has been a consistent and decided change towards full automatic operation instead of a predicted increase in manual assistance.

The experience with the traffic distributor which is the last change in this direction, is of interest because it either proves that this style of equipment is exceedingly efficient, or that the time and effort required to select a number by means of the automatic dial, is not as great as is generally supposed. Most likely, due credit should be given one and criticism spared the other. At any rate, it seems to form an efficient link between the manual and automatic part of the plant.

In view of the development of automatic private branch exchange service in other cities, it is rather surprising that the Los Angeles Company has so long retained a manually operated board for the trunking of private branch exchange calls. If it is found practical and economical to select the numbers by

means of the automatic dial at the traffic distributor, it should be just as practical to select them directly from the private branch exchange board. It may be objected that by so doing an additional load will be placed upon the private branch exchange operator. Experience has proved, however, that such is not the case. When telephones connecting with the private branch exchange board are equipped with automatic dials, and the exchange trunks are so designed that the private branch exchange patron may either ask the operator for a trunk line and then select the number by means of the dial on his telephone, or he may ask the operator to obtain the number for him, it is found that about 90 per cent of the calls will be selected from the telephone. After the patrons have become accustomed to the use of the automatic telephone, about the only calls that the private branch exchange operator will be asked to handle are calls where it is not definitely known where the desired party is to be found, and it may take some time to locate him. In such cases, several numbers may be called in rapid succession by the operator before the party is located, and that can be accomplished quicker by automatic than any other method of trunking. It is, therefore, evident that though there may be a loss of time in some connections as compared with manual connections, there is a decided gain in others.

Just as in the case of private branch exchange service the tendency has been toward direct automatic trunking, so in the case of toll service there has been a tendency toward direct automatic operation over the toll lines. Electrical impulses sufficiently reliable to operate the automatic switches can be transmitted over any lines that will permit operation of telegraph relays. It therefore follows that automatic operation is possible over any circuits that will permit operation of the well-known principle of combined telephony and telegraphy. Extended service tests have proved that there is a considerable gain in the efficiency of the circuits by this method of operation on distances that will permit what is known as the "single ticket" method of operation. Many agressive independent telephone companies are at present extending its use, and it is evident that its efficiency has also been recognized in Los Angeles.

DISCUSSION ON "ABNORMAL VOLTAGES IN TRANSFORMERS" (WEED), SAN FRANCISCO, CAL., SEPT. 17, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915.)

(Subject to final revision for the Transactions.)

R. W. Sorensen: I wish to bring before this transmission session the outline of a method of eliminating by means of transformers, abnormal voltages in an extensive high-voltage transmission and distribution system operating in Southern California.

This system when completed was practically as is shown in Fig. 1, with this exception: at the station marked "Vernon" there was no bank of transformers installed for the suppression of disturbances as given in the diagram. Thus it will be seen that the distribution network was made up of approximately 250 miles of 18-kv. line and 100 miles of 60-kv. line, all three-phase, and interconnected at Eagle Rock, as shown, and also at Vernon and at another point 50 miles from Vernon through delta-delta transformer banks, these latter connections not being shown in the diagram. Added to this there is, of course, the 3-phase, 150-kv. transmission line feeding the Eagle Rock station.

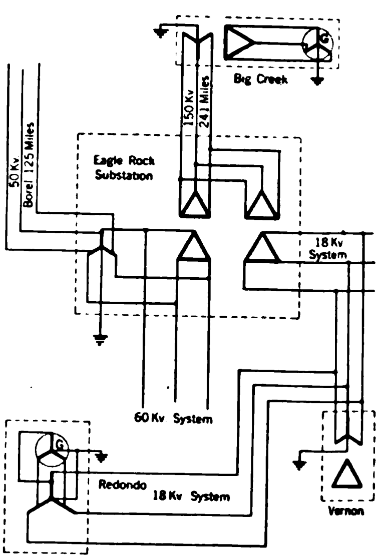


FIG. 1

At a number of points on the 18-kv. system are substations stepping the voltage down from 18,000 to 2400 volts for local distribution. Shortly after the entire system including the 150-kv. and the 60-kv. lines had been put into service, there were a number of serious interruptions disastrous both to service and apparatus. These interruptions were due to discharges from the 18,000-volt lines to ground in various parts of the 18,000-volt system, there being apparently no definite point of discharge. When these discharges occurred and one phase of the lines was thus grounded there usually followed one or more other discharges at various points on the system, these subsequent break-downs or grounds, as we termed them, occurring frequently as far as 50 miles away from the point of the first ground. An examination of the places where these resulting or secondary grounds occurred showed clearly in a number of cases the so-called "spatteration" effect so often produced by high-frequency discharges. Further, the distances jumped by these discharges forming the grounds indicated either very high-frequency surges or wave fronts of alarming potentials in the system. In

fact, so certain were we of the evidences that such high-frequency disturbances were taking place that without resorting to oscillograph tests we came to the conclusion that some means must be provided to absorb the surges starting from a ground occurring some place on the system.

Some of my former experiences naturally led to the adoption as a means of accomplishing this result of a bank of transformers connected star-delta, as shown in the station marked Vernon on the diagram previously referred to. In this particular instance there was already at Vernon three 5000 kv-a. transformers rated 60,000 volts high tension and 15,000 volts low tension, which were not in use. These transformers were arranged in a three phase bank, the low tension windings being connected star with the neutral grounded, and the high tension windings connected delta. The low tension terminals of the bank were then connected to the 18,000-volt 3-phase system, the high tension delta connection being left to float free rather than being connected to any lines of the system, thereby being allowed to serve entirely the purpose of a damping circuit for any unusual high frequency current tending to flow between one phase of the 18,000-volt 3-phase system and the neutral should a phase for any reason become grounded. More than a year of operation with this arrangement with less trouble than occurred in two weeks before it was put into service has demonstrated its entire success on this system in confining the damage done by grounds definitely to the point of first ground, thus making the trouble a local trouble rather than one involving the entire system. This was accomplished by damping out by circulating current in the bank of transformers the energy of surges set up when one phase of a system in which there is a comparatively large amount of electrostatic capacity becomes grounded, rather than allowing this energy to take the form of high voltage strains resulting in more or less damage to the system and involving the entire system in a shut-down. I think, also, that the ground connection on this auxiliary bank of transformers at Vernon for the suppression of high frequency oscillations has been of great assistance in eliminating the number of primary or fundamental arc overs to grounds occurring on the system, because it has served to equalize the electrostatic potentials between the different voltage distribution networks and the ground.

I should like to point out in this connection the fact that this experience has led me to the definite conclusion that in any large network of high-voltage distribution it is impossible to continue the operation of an isolated delta system without a shut-down, due to disturbances, when one phase of the system becomes grounded.

F. F. Brand: From Mr. Weed's paper it appears that any type of transformer winding is liable to have these excess voltages produced in it. Now it therefore appears that if these

excess voltages do not do any damage the oscillation must be dampened out before these voltages can rise to high enough values to puncture the insulation.

It seems to be a general conclusion among many operating men that troubles due to surges occur more readily when lines are lightly loaded than when they are heavily loaded, although Mr. Weed does not make that point in his paper. I would like to ask him if he thinks that the extra losses due to hotter lines and hotter transformers, that is, increased copper loss and perhaps more particularly the tremendous extra loss in the insulation which occurs at the higher temperatures under load, account for this apparent effect of dampening out surge voltages.

Percy H. Thomas: There is a well known condition in which trouble such as Mr. Sorensen describes would occur from that sort of connection without the existence of any particular surges, and perhaps he can tell us off-hand whether that may be the condition; that is to say, if we have 150,000-volt transmission system and lowering transformers, we will say, 15,000-volt secondaries, and the circuits connected to the secondaries are not definitely grounded at any point, then by virtue of the electrostatic capacity between the primary and secondary windings of the step-down transformers any disturbance of the potential on the 150,000-volt circuit would tend to produce a high electrostatic potential on the 15,000-volt circuit. That would cause such demonstrations as he speaks of. This condition of induction must be met in all circuits, of course, where the 15,000-volt or the secondary system is one of small electrostatic capacity. You could not operate such a small capacity system without a dead ground or a lightning arrester on the secondary circuit.

I would like to ask whether there was any ground on the circuit in the present case before this addition of the 60,000-volt and 15,000-volt transformers, and whether it is not possible that the grounding of this circuit was sufficient to eliminate the trouble merely by keeping the 15,000-volt circuit at its normal potential.

R. W. Sorensen: I would answer Mr. Thomas's inquiry by saying that both the ground and the delta secondary are necessary at Vernon, as there appeared to be no difference in the severity of the disturbance with or without the ground connection at Redondo, as shown on the diagram, prior to the installation at Vernon of the transformer arrangement for the suppression of disturbances. Some of the disturbances, which occurred apparently without any definitely determinable provocation, must undoubtedly have been occasioned by the very thing mentioned by Mr. Thomas, as then the discharge of the large line capacitance through the inductance of the line and ground thus formed would generate enough voltage to give one or more other breakdowns to the ground, there being in a few cases a half dozen or more grounds occurring at apparently the same time, the lightning arresters at such time appearing to be no good, because these high-frequency discharges were beyond their range of operation.

I might add that although no oscillograph tests were made directly on the system, laboratory tests under conditions approximating those of the system were made, oscillograms of which showed well the remarkable smoothing up of current and voltage waves in the system by the introduction of a bank of transformers connected in the manner described in my discussion.

J. M. Weed: Mr. Brand's question brings up a point which may not have been properly emphasized in the paper, namely, that the voltages found by the calculations and represented by the curves are not produced in the actual transformer. This is principally due to two things, first, the fact that in practise high-frequency wave trains are not sustained long enough to produce these maximum voltages, and second, the fact that the internal losses, which have been neglected in the calculations, are active in absorbing the energy which produces these voltages. The greater these losses, the smaller will be the voltages which are produced. The most important element of these losses is the dielectric loss in the insulation, and since this loss increases very rapidly with increase of temperature the voltages produced in a hot transformer by a given high-frequency disturbance will certainly be lower than those produced in a cold one. In so far, therefore, as the temperature of a transformer is raised by its load, the internal voltages produced by high-frequency disturbances will be reduced thereby.

DISCUSSION ON "DELTA-CROSS CONNECTION OF TRANSFORMERS" (ROUX), SAN FRANCISCO, CAL., SEPT. 17, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915.)

(Subject to final revision for the Transactions.)

E. E. F. Creighton: This double connection of two-phase and three-phase is a great convenience where so many of the systems in the country are being changed over from two-phase to three-phase. There are certain disadvantages in the two-phase system, notably the greater number of surges which occur. Without analyzing the difference, we give it recognition practically by the fact that in a two-phase system of the same voltage as a three-phase system, we have to use more gaps in series in the multi-gap arrester.

W. A. Hillebrand: This connection described by Mr. Roux has been used by the Pacific Gas & Electric Company for at least ten years.

A case came up, three 100-kw. transformers wherein the unbalancing of the two-phase load came to as much as 12 per cent, leading to very considerable distortion, and by rearranging connections the transformation unbalance was reduced from 12 per cent to $1\frac{1}{2}$.

There is one other point I would like to speak of in connection with Mr. Roux's analysis of currents that flow in the different windings. He has omitted altogether the effect of the regulation of the leading and lagging currents.

L. F. Blume (by letter): The transformation of power from three phase to two phase or vice versa has been subject for discussion from time to time ever since the T transformer connection was introduced. Since then a host of transformer connections has been proposed to accomplish the same purpose; but in spite of all these proposals there have been but few changes from the original method, undoubtedly due to the fact that the T connection, in addition to being the simplest of all, at the same time is a very efficient method, and very little room for improvement was left.

Mr. Roux in his very interesting paper shows how the T-connected auto-transformer has been practically applied to the interconnection of two-phase four-wire voltages and three-phase voltages, in which the two-phase and the three-phase voltages are equal. This problem being a particular case of a general proposition, the general solution may be of interest. Figs. 1, 2, 3, give the general solution for the four-wire two-phase system, and Figs. 4, 5, 6, the general solution for the three-wire two-phase system (three-wire L connection). The figures are self-explanatory, and the equations give the currents flowing in sections a, b, c, d, of the windings in terms of the two-phase current I, the three-phase voltage E, and the two-phase voltage E''.

In general, seven wires are needed to operate the T connection and six wires to operate the three-wire L connection, but, by choosing the proper ratio of transformation, these wires may be

T CONNECTION.

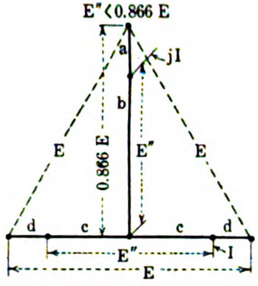


FIG. 1

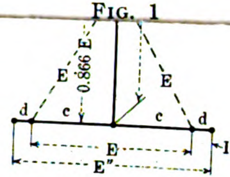


FIG. 3

(a) $I = [0 + j]\,I$

(b) $\left(1.155\,\dfrac{E''}{E} - 1\right) I = \left[0 + j\left(1.155\,\dfrac{E''}{E} - 1\right)\right] I$

(c) $\sqrt{1.33\,\dfrac{E''^2}{E^2} - 2\,\dfrac{E''}{E} + 1}\;\; I = \left[\left(\dfrac{E''}{E} - 1\right) + j\,\dfrac{E''}{1.73E}\right] I$

(d) $I = [0 + j]\,I$

3 WIRE L CONNECTION.

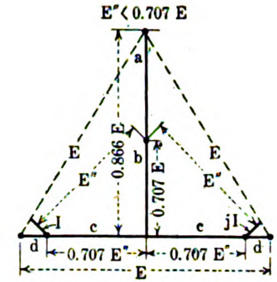


FIG. 4

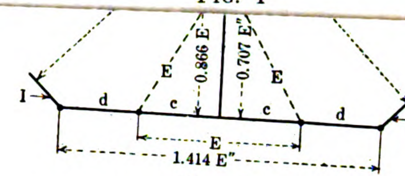


FIG. 6

(a) $1.414\,I = [1 + j]\,I$

(b) $\left(1.155\,\dfrac{E''}{E} - 1.414\right) I = \left[\left(.817\,\dfrac{E''}{E} - 1\right) + j\left(.817\,\dfrac{E''}{E} - 1\right)\right] I$

(c) $\sqrt{1.33\,\dfrac{E''^2}{E^2} - 2.23\,\dfrac{E''}{E} + 1}\;\; I = \left[\left(1.115\,\dfrac{E''}{E} - 1\right) + j\left(.298\,\dfrac{E''}{E}\right)\right] I$

(d) $I = [1 + j\,0]\,I$

reduced to four. In the T connection this ratio (two-phase line voltage divided by three-phase line voltage) is unity, and 0.707 in the three-wire L connection, the former being the case discussed by Mr. Roux and shown in Fig. 3 of his paper.

Whether the " delta-cross " connection as described and shown in figures 5, 6, 7, of Mr. Roux's paper is preferable to the T connection would depend entirely on the particular case involved. Referring to Fig. 5, of his paper, it is evident that for three-phase to three-phase transformation, it is a simple delta-delta connection. Therefore, if the major load were a three-phase load, this connection would be very desirable and probably more efficient than the T connection but, if the major load were two-phase, the T connection would be superior, since for three-phase to two-phase transformation, the delta-cross connection is not very efficient.

Moreover, there are several disadvantages of delta-cross connection which Mr. Roux has not mentioned. First, the winding with the 50 per cent tap must have the two halves interlaced with respect to each other, so that the two-phase currents which flow in one direction in the one half and in the opposite direction in the other half may not introduce undue reactance drop. Second, just what the relative capacities of the three transformers should be, depend upon the division of the currents within the transformers. This, however, cannot be worked out without presupposing a definite power factor of load. On the assumption that the load power factor in the two-phase and three-phase circuits are entirely independent, it is possible to have cases where the current in any given winding due to the two-phase load is in phase with the current due to the three-phase load. This being the case, each winding should be designed for the numerical sum of the two-phase and three-phase currents. Only when the power factors of the two loads are definitely known, would it be safe to use smaller units. On account of these limitations, it is doubtful whether transformers unless specially designed for the purpose can be economically used for this connection.

An article in the *General Electric Review* of Sept. 1912 gave a general solution for a large number of cases of these connections.

G. P. Roux: The object of my paper was to present to the members of the Institute the benefits of the experience acquired in the operation of a multi-phase system of distribution permitting, without undue complications, to supply two-phase and three-phase energy simultaneously through only four wires and from one single bank of transformers. These requirements were imposed by existing conditions pending changes in distribution lines and equipment that could be made only in the course of time so as to standardize the system to a three-phase distribution, the stand-by generating station remaining, however, two-phase.

This problem was solved very successfully with the use of

the delta-cross system of connection and subsequently applied to a number of other similar cases with equally satisfactory results.

Although Mr. Blume entertains technical doubts as to the advisability of this system of connections and also as to its efficiency, I wish to offer as an evidence, a 1500-kv-a. bank of transformers —not even specially designed for this purpose, although with windings sufficiently interlaced so as to have the same ratio of impedance, a feature that we now expect in all transformers of modern construction—which has been in successful operation now for four years supplying with light and power part of a city of 50,000 inhabitants, and it is worthy of note that in so far as regulation of either the two-phase or three-phase circuits and efficiency are concerned, this system of connection has exceeded all expectations.

Numerous tests made under different operating conditions of loads and power factors leave no doubt as to the efficiency and convenience of this method of connections for cases where two-phase and three-phase currents must be supplied.

To be presented at the 321st meeting of the American Institute of Electrical Engineers, Washington, D. C., April 26, 1916.

ELECTROCHEMICAL INDUSTRIES AND THEIR INTEREST IN THE DEVELOPMENT OF WATER POWERS

BY LAWRENCE ADDICKS

ABSTRACT OF PAPER

The electrochemical industries have grown to be of great value to this country; they have a fundamental interest in the development of cheap power; they offer nearly ideal power loads of magnitude; they must be located strategically as regards supplies and markets; Niagara power is not cheap enough nor is it sufficient in its present state of development to afford growth to these industries; the industries have so far been hardly strong enough to develop large powers themselves; great expansion should follow the development of cheaper power in accessible locations; and the country is vitally interested in the development of the nitrate industry, which must have very cheap power in great quantity in order to exist. In view of all these considerations, a liberal water power policy on the part of the government would seem to be a step in the right direction.

THE INDUSTRIAL processes founded upon electrochemistry have a part in the manufacture of a very wide range of commercial products. By definition they all require electric power in greater or less quantity and in many instances power is a large item in the cost sheet. The power requirements vary enormously, however, in different cases, and many other considerations enter into the determination whether a given industry can flourish in a given location. It is the purpose of this paper to point out briefly the interrelation of some of these factors and the interest the industries have in the development of cheap power.

The electric current may be used for its chemical effect, giving oxidation products at the anode and reduction products at the cathode in an electrolytic cell; or it may be used for its heat effect in an electric furnace, where high temperatures and a controlled atmosphere are desirable; or both effects may be utilized, as in the electrolysis of fused salts. Finally, we have the effects of electric discharges through gases.

It is not generally appreciated to what extent electrochemical processes have entered into some phase, at least, of nearly every branch of our industrial life. A small beginning in electro-

Manuscript of this paper was received March 28, 1916.

plating two generations ago has developed until the great majority of the copper output of the world is electrolytically refined; silver is thus parted from gold and gold from the platinum metals, bismuth-bearing lead can be successfully treated, electrolytic nickel is well known, and zinc and tin so refined are appearing in the market. In general, electrolytic refining not only increases the purity of the metal but makes possible the recovery of the impurities as byproducts, thus greatly cheapening the cost of some of the less common elements.

The electrolysis of common salt is the basis of the electrolytic alkali industry, the products of which are caustic soda, the starting point for various chemical industries, and used in very large quantities in soap making, mercerizing cotton, etc.; metallic sodium, also used as a foundation for other products, such as the cyanide so largely used in the metallurgy of silver and gold; chlorates, used in the manufacture of matches, certain explosives, etc.; hypochlorites, of value for bleaching; chlorine, employed as a sterilizing and chloridizing agent and for the formation of bleach.

The electric furnace has created a host of new industries. Very briefly, the chief products consist of abrasives, such as carborundum, alundum, aloxite, etc.; graphite; silicon; ferro-alloys, such as ferro-silicon, -manganese, -chrome, -tungsten, -vanadium and others, which are used in the steel industry for producing sound ingots, hardening, making special steels, high-speed tool steel, armor plate, etc.; refined steel of crucible grade; phosphorus by distillation; calcium carbide, used in the generation of acetylene and in the manufacture of cyanimid; and so on. It is also being tried out experimentally as a competitor of the combustion furnace in the metallurgy of many metals. Used as an electrolytic furnace, we have the very important application to the production of aluminum.

The industrial use of electric discharges through gases is still in its infancy, but we have ozone and nitric acid among the products, the former used for sterilization and the latter as a base for fertilizers and explosives.

This brief review of electrochemical products is by no means exhaustive. If it were followed to a logical conclusion and a list made of all the uses of all the products it would be a formidable affair, but I think enough has been said to establish the first point that I wished to make, namely, that electrochemistry today plays a large part in our industrial life and that its industries are more important than the public at large realizes.

Now every one of these industries consumes large quantities of energy. Starting at the bottom, we have the refining of lead at 120 kw-hr. per ton, and of copper at 300 kw-hr. per ton. Where diaphragms are used, as in nickel refining, the power rises to about 3000 kw-hr. per ton. Where insoluble anodes are used for the recovery of a metal from solution, the power will range from 700 to 4000 kw-hr. per ton, depending upon the metal, the amount of depolarization at the anode, and of course the current density.

Turning now to electric furnaces, an ordinary melting operation, such as casting an alloy or refining steel, generally requires from 600 to 1000 kw-hr. per ton. In the production of ferro-alloys, which is really a smelting operation, a large amount of energy is consumed by the endothermic reaction, and the power used runs from 3000 to 8000 kw-hr. per ton of product, depending upon the grade of alloy made. The aluminum furnace requires 25,000 kw-hr. per ton of product. The electrolytic refining, alkali and aluminum industries require direct current; the graphite, carborundum, melting and ferro-alloy furnaces use alternating current. In general low voltage and high amperage is employed. In the case of alternating current this is readily obtained by the use of suitable transforming units; in the direct-current processes it is customary to connect a sufficient number of cells or furnaces together to obtain a reasonable line voltage. Individual industries in plants of modern commercial size require blocks of energy ranging from 5000 to 50,000 kw-hr. and it is self-evident that the charge for energy in such quantities is a vital item in the cost sheet. And this brings us to the question of what is cheap power.

Twenty years ago Niagara power was cheap, but in the meantime steam power has made such strides that Niagara and similar water power developments can no longer be considered the exclusive sources of electrolytic power. In so speaking I am of course not considering the very low rates which were made on a few contracts in the early days at Niagara, but of the present rate of about 0.3 cent per kw-hr. ($20 a horse power-year). With the very high economy of the large turbo-alternator it is quite possible to meet this figure by locating a plant near some of the coal fields. It is therefore idle to discuss any new source of power higher in cost than Niagara.

It is often suggested that electrolytic plants could be operated to advantage on off-peak power. This is seldom practical. In the first place, to shut the power off for several hours in many

cases creates very undesirable chemical conditions; then, in most electric furnace processes there is a loss of heat while standing which calls for the expenditure of excess energy upon starting up; and finally, there is the loss of production due to several hours' idleness to be reckoned with, and in this connection it must be remembered that electrolytic plants generally call for heavy investments, the fixed charges on which need every possible ton to divide by. After these handicaps are properly allowed for, it is only in exceptional cases that a mutually satisfactory contract can be made.

And then we have the power contract to deal with. The owner of the water power generally requires that a fixed minimum annual sum shall be paid regardless of consumption. This is naturally a little hard on periods of low output. On the other hand, excess power is apt to be either subject to prior sale or charged at an excess rate, so that the manufacturer has to balance his output on the tip of his nose, so to speak, if he is going to realize the advertised rate per kilowatt-hour.

Next, we have the difficulty that the power is invariably sold as high-tension alternating current, which imposes various conduction and conversion losses on the purchaser which may easily absorb 15 per cent of the incoming power. The transformers and other apparatus represent a considerable investment, shattering another illusion—that the "other fellow" had to put up all the money. Then in some contracts we mustn't unbalance the phases or let the power factor run off.

By the time all these allowances are made, the power originally spoken of as 0.3 cent per kw-hr. is nearer 0.4 cent, plus a considerable investment, a figure which begins to approach the cost of steam power in the vicinity of New York City, using buckwheat coal; and, as before stated, Niagara Falls is no longer bargain power. This statement leads to a number of questions about as follows:

(1) If cost of power is the great consideration, and Niagara Falls has no longer the cheapest power, why do all the electrochemical industries remain grouped there?

(2) If electrochemical industries have been able to thrive on present power costs, is not the cry for cheaper power merely one for additional profits?

(3) We have in this country a variety of fuel supplies: why are not great central stations established in some of these fields if the resulting power could cost less than water power?

In endeavoring to answer some of these questions, I hope to

bring out the main factors which have to be considered in establishing an electrochemical industry.

As to the first question, the cost of power, while important, is by no means the whole, and often not even the controlling, factor and Niagara, while an electrochemical center, is not the sole residence of such industries. There are three main factors to be considered in locating such an industry; transportation, labor and power; and in reality power may be placed under the transportation heading, leaving but two. In any industry, raw materials must be carried to the manufactory and the finished products to their markets. As fuel can be carried and electric current can be transmitted, it is evident that the increased cost of power due to such movements is simply a freight item. The moment this is realized the problem does not differ from that presented by any other manufacturing operation. Where raw materials are bulky and the product and power used are not, the work will be carried on near the source of the raw material, as in the case of a plant for reducing copper from its ores. Where power or fuel is bulky it may become the controlling factor. In zinc metallurgy, for example, the ores are rich and it takes three tons of coal to smelt one ton of zinc. Zinc smelters are therefore located in the fuel belts. An electrochemical instance is aluminum. Here the ore is carried great distances in order to avoid the transmission of 25,000 kw-hr. per ton of aluminum produced. Then again, the process may not greatly change the bulk of the raw materials, as in refining operations, but transportation still governs. In electrolytic copper refining the plants are, with a single exception, at tide water. Here the Western smelters bring the product up to 98 per cent copper. There is but little dead weight in transporting this crude copper, and the silver and gold contents if separated at the smelter would have to travel by express. Also labor and power are cheaper at tide water where the market is, than in the Rocky Mountains where the smelters are. The one exception at Great Falls, Montana, is where an exceptionally cheap water power exists at the smelter, precious metal contents are low, and there is the possibility of considering Western markets and movements via the Panama canal. Finally, labor is a large item. If we assume that a man earns $3.00 a day and that power costs 0.3 cent a kw-hr., the two are of equal importance when an industry uses, on a 24-hour day, 42 kw. per employee. By no means all the electrochemical industries use such a proportionate amount of power. I think enough has been said to

show that an appreciation of geographical values is of the utmost importance and that power is of purely relative value.

If we examine the industries grouped around Niagara Falls, we shall find that practically all of them have been created in the last 25 years; that many of them use as raw materials such things as carbon, salt, silica, etc., which are obtainable within a reasonable distance; and that they are chiefly those electric furnace operations which rate among the larger power consumers in the electrochemical list. Now, the investment called for in electrochemical plants is generally high, and it can be readily understood that it is a very welcome lessening of obligation in starting a new industry to be able to cut out the money which would be tied up in a private power plant. Also, really low costs on steam power can not be obtained until a load of about 15,000 kw. is built up. Then, Niagara Falls is in a strong location as far as transportation facilities are concerned. Water transportation through the Great Lakes is at hand and Buffalo is a railroad center. The labor market is also good.

As to the second question, whether 0.3 cent per kw-hr. is not low enough to allow any electrochemical industry to thrive, it is simply a matter of competition. Useful as electrochemical products have proved, they are not necessary to sustain life; we got along, after a fashion, a quarter of a century ago before most of them were heard of. We must remember, however, that every one of these products has had to win its way against competition. Graphite and the abrasives have had to compete with natural graphite and emery; aluminum had wood and copper to displace; the alkali products can be produced chemically; the ferro-alloys can be made in blast furnaces; electrolytic refining had fire methods to compete with; electric steel refining replaced the crucible method; and so on. It is quite conceivable that power costs should be so high that the older processes in some cases might revive. On the other hand, electrochemical processes are in their infancy and a decrease in the cost of power is bound to stimulate new lines of production. It is quite within the range of possibility that many of the combustion furnaces now used in metallurgy can be some day replaced by one or another type of electric furnace. Hydrometallurgy, which is closely linked with electrodeposition, has also a large field before it. The question of electrical action on gases is a most promising possibility for development. Take the fixation of atmospheric nitrogen, one of the largest technical problems which this nation has to face today. We import large quantities

of Chilean nitrate every year. Our only local sources are decomposing organic matter and a small quantity of byproduct ammonia salts. Nitrogen is a necessary constituent of fertilizer and is the base of all explosives. The military recklessness of being forced to depend upon imported material for the manufacture of ammunition in these troublous times has recently brought this question very much to the front. There are several methods of fixing the nitrogen of the atmosphere in use abroad. Two of these processes, the oxidation of nitrogen in the electric arc and the conversion of calcium carbide into cyanimid, are suitable for commercial development in this country, and in fact there is already a large plant devoted to the cyanimid industry at Niagara Falls, Canada. The arc process requires large quantities of electric power; several hundred-thousand horse power are so used in Norway. The cyanimid process, while chemical, requires calcium carbide, an electric furnace product, as its raw material. As matters stand today it may be necessary for the government to subsidize this industry to guarantee its required supply of explosives in time of war. If we had 500,000 h.p. available at say 0.15 cent a kw-hr., (a common figure in Scandinavia) this great industry would develop at once on a peace basis on account of the fertilizer demands.

As to the third question, our electrochemical industries are either buying from some water power company or they are generating power themselves from steam. The water power company naturally sells its output for all that it will bring, with a weather eye on the local cost of steam, and very few industries are large enough to save this profit by operating their own hydraulic plants. Unfortunately most of our high-head water powers, which are capable of development on a small scale and with moderate investment, are on the Pacific coast where markets do not yet exist for many electrochemical products. Most of the latter are of such a nature that they serve only as raw material in manufacturing operations conducted chiefly on the Atlantic seaboard. The time may come when various electrochemical industries will associate in a cooperative power development. In this case the eastern coal fields will be carefully considered, especially as many of the processes require large quantities of coal for operations entirely apart from electrochemistry, such as evaporating or heating liquors, reverberatory smelting, etc. Near a sufficient and suitable supply of water for boiler feed and condensing, and close to the coal mines, a mammoth steam plant could certainly give a lower power cost than now

obtainable at Niagara. Perhaps the chief objection to such a scheme would be the present unsatisfactory labor situation in the coal fields.

Then we have the various propositions depending on the use of gas. Natural gas is fast disappearing and can no longer be considered for such a plan. The beehive coke oven, which used to be held up as a glaring example of heat waste, is also rapidly giving place to various retort types. The use of producers supplying gas engines begins to lose its attractiveness as the cost of fuel decreases, and placing the steam plant near the colliery deals a heavy blow to this scheme, which offers low fuel consumption as an offset to great first cost and lack of overload capacity. The byproduct coke oven is more attractive, but so far it has been linked up with either the iron and steel industry or the production of illuminating gas, and it is not very desirable to be tied up with another industry and run the danger of being subject to the ups and downs of industrial prosperity in an unrelated field. Then we have our peat deposits, which somehow never seem to receive really serious consideration.

If we knew that there was no hope of getting lower water power costs, I believe some great central power plant would eventually be established. The two stumbling blocks at present in the water power question are government control and the great cost of developing low-head powers. One possible way of meeting the latter difficulty is to consider the value of the development from other points of view, such as irrigation, navigation or flood prevention. All the power plant wants is the potential energy in the water.

Summing up, the electrochemical industries have grown to be of great value to this country; they have a fundamental interest in the development of cheap power; they offer nearly ideal power loads of magnitude; they must be located strategically as regards supplies and markets; Niagara power is not cheap enough nor is it sufficient in its present state of development to afford growth to these industries; the industries have so far been hardly strong enough to develop large powers themselves; great expansion should follow the development of cheaper power in accessible locations; and the country is vitally interested in the development of the nitrate industry, which must have very cheap power in great quantity in order to exist. In view of all these considerations, a liberal water power policy on the part of the government would seem to be a step in the right direction.

To be presented at the 321st meeting of the American Institute of Electrical Engineers, Washington, D. C., April 26, 1916.

WATER POWER DEVELOPMENT AND THE FOOD PROBLEM

BY ALLERTON S. CUSHMAN

Abstract of Paper

The great increase in population of the United States has been chiefly in urban districts while the increase in population in rural districts has been comparatively small. This results in a continuously growing demand for food with a relatively small proportion of our population as food producers. The production of some of our most highly nitrogenous food products has been steadily declining and American farmers have been producing less per acre than European farmers.

The food supply depends in the last analysis upon the plant food supply. The production of nitrogen, which is one of the three principal fertilizer ingredients, is distinctly a water power proposition involving the fixation of atmospheric nitrogen. More than 80 per cent of mixed fertilizers produced in the United States is used east of the Allegheny Mountains, and for the fertilizer problem the water power must be developed in those parts of the country where the demand for intensive agriculture exists. A feasible and proper plan for water power development in this country will have a profound influence on the development and distribution of cheap fertilizer ingredients which are so necessary under modern intensive conditions in the growth of population and its relation to agriculture.

IN OUR centennial year 1876, just forty years ago, Thomas Huxley, the great English scientist, delivered the dedicatory address at the formal opening of the Johns-Hopkins University in the City of Baltimore. In the course of this address he gave utterance to the following pregnant words:

To an Englishman landing upon your shores for the first time, traveling for hundreds of miles through strings of great and well-ordered cities, seeing your enormous actual, and almost infinite potential, wealth in all commodities, and in the energy and ability which turn wealth to account, there is something sublime in the vista of the future. Do not suppose that I am pandering to what is commonly understood by national pride. I cannot say that I am in the slightest degree impressed by your bigness, or your material resources, as such. Size is not grandeur, and territory does not make a nation. The great issue, about which hangs a true sublimity, and the terror of over-hanging fate, is what are you going to do with all these things? What is to be the end to which these are to be

Manuscript of this paper was received April 2, 1916.

the means? You are making a novel experiment in politics on the greatest scale which the world has yet seen. Forty millions at your first centenary, it is reasonably to be expected that, at the second, these states will be occupied by two hundred millions of English-speaking people, spread over an area as large as that of Europe, and with climates and interests as diverse as those of Spain and Scandinavia, England and Russia. You and your descendants have to ascertain whether this great mass will hold together under the forms of a republic, and the despotic reality of universal suffrage; whether state rights will hold out against centralization, without separation; whether centralization will get the better, without actual or disguised monarchy; whether shifting corruption is better than a permanent bureaucracy; and as population thickens in your great cities, and the pressure of want is felt, the gaunt spectre of pauperism will stalk among you, and communism and socialism will claim to be heard. Truly America has a great future before her; great in toil, in care, and in responsibility; great in true glory if she be guided in wisdom and righteousness; great in shame if she fail. I cannot understand why other nations should envy you, or be blind to the fact that it is for the highest interest of mankind that you should succeed."

Thus spake, almost half a century ago, one of the most prescient and philosophic minds that the world has yet produced. Our population has already risen from forty to one hundred million people, and it is our present, as well as our future task, to feed not only our own teeming populations, but also, in some large measure, a war stricken Europe, and, from time to time, a famine stricken Orient. It is well that we should examine our resources and review what we have done or are about to do with our heritage. "What are you going to do with all these things?" "What is to be the end to which these are the means?"

It is not my present intention to inflict upon this audience a multiplicity of statistical data, but some significant figures must be here referred to as an introduction to the points that are to receive special consideration in later paragraphs. In consulting the statistical data, I have purposely confined myself to government publications of date not later than 1914. The great European struggle, breaking out in the fall of that year, rendered all world conditions unstable and artificial, so that statistics of war years may easily be confusing and misleading.

In the annual report of the United States Secretary of Agriculture, for 1914, we learn that although the population of the United States has increased twenty-three million in the past fifteen years, the strictly rural districts have shown an increase of barely six million. More mouths to feed with fewer husbandmen, is perhaps *the* most important problem of our most modern age.

Again, from our conservative Secretary of Agriculture we

learn that: " While there is an increased diversification of agriculture, and both a relative and absolute increase in important products, such as wheat, forage crops, fruits, dairy products and poultry, we have to take note not only of a relative but an absolute decrease in a number of our staple food products such as corn and meats. In the former in the last fifteen years there has been no substantial advance. In cattle, sheep and hogs there has been an actual decline—in cattle, from the census year of 1899 to that of 1909, from 50,000,000 head to 41,000,000; in sheep from 61,000,000 to 52,000,000; in hogs from 63,000,000 to 58,000,000. Since 1909 the tendency has been downward, and yet during the period since 1899, the population has increased over 20,000,000. This situation exists not in a crowded country but in one which with 935,000,000 acres of arable land, has only, 400,000,000, or 43 per cent, under cultivation, and in one in which the population per square mile does not exceed 31 and ranges from 0.7 person in Nevada to 508 in Rhode Island. Just what the trouble is no one is as yet sufficiently informed to say. It can scarcely be that the American farmer has not as much intelligence as the farmer of other nations. It is true that the American farmer does not produce as much per acre as the farmer in a number of civilized nations, but production per acre is not the American standard. The standard is the amount of produce for each person engaged in agriculture, and by this test the American farmer appears to be from two to six times as effcient as most of his competitors. Relatively speaking, extensive farming is still economically the sound program in our agriculture, but now it is becoming increasingly apparent that the aim must be, while maintaining supremacy in production for each person, to establish supremacy in production for each acre."

In other words, and I am now speaking for myself, extensive agriculture must ultimately be practiced in an intensive manner, if the food supply of an ever-growing population is to be economically produced. I have no desire to take issue with the Secretary of Agriculture in respect to what he has said about the efficiency of the American farmer. We cannot, however, overlook the fact that European farmers are obtaining higher yields per acre on the self same soils that supported our own ancestors before their emigration across the seas, perhaps centuries ago, whereas our own agricultural operations began on virgin fields which in too many instances are already run down if not abandoned. If these things are so, lack of efficiency and careless

methods of agriculture must be held at least in part responsible for present conditions. It is, however, manifestly unjust to shift the full burden of blame on to the shoulders of the American farmer. Upon capital and government should fall the fuller measure of responsibility in not having long ere this sought methods of providing more abundantly the plant food requirements of the soil. If it is true that before the war Belgium's crops showed the highest yield per acre, it is also true that the Belgian acres used the highest pro rata quantities of intensive fertilizers. It is at least comforting to learn that the total production in 1914 of our own United States in its six leading cereals, aggregated nearly five billion bushels. But in spite of these overwhelming figures, it is foolish to close our eyes and shut our ears to the conditions that have to be met in the face of an ever-growing population and a relative and actual decline in the most highly nitrogenous food products. It is truly written that man does not live by bread alone. Green vegetables and the fruits of the earth, especially those with a high nitrogen content, are and will continue to be as intensively demanded as the cereals. The high cost of living, a most living issue, is pressing its influence upon the consideration of political parties and platforms, but no legislation can correct, no political promises overcome a condition which rests solidly upon the world-old principle of growing demand and diminishing supply.

At this point I wish to take the occasion to state most emphatically that I am not preaching a Malthusian doctrine of hopelessness. If this statement is not made here with sufficient emphasis, it will be said that we, a deliberative body, are looking forward to a condition of imminent starvation. Nothing could be farther from the truth than this. At the present time we are producing in abundance nearly every product and produce that is necessary for our present sustenance and development. I believe that this will always be true, but in order to make it true, thoughtful men will study the conditions and needs of the future and prepare to meet them in advance. To do less than this is to be false to our country and to our posterity.

The question of an adequate food supply for a growing population resolves itself, in the last analysis, into an adequate plant food supply. Unless we feed the herbiage of the earth, we cannot feed ourselves. As almost everyone knows, the three principal plant foods are fixed nitrogen, compounds of

the element potassium, generally referred to as potash, and phosphates. For our principal supply of the first two of these mineral plant foods, we are, as is now very generally understood, mainly dependent on foreign sources. It is just this lack of a native supply which the chemists and the engineers of the country are prepared to meet, just as soon as the powers that control our capital, finance and legislation have adjusted their differences of opinion and become prepared to order the work to go on. The main reservoir on which we must draw for our supplies of fixed nitrogen in the future, both for agriculture and for national defense, must be the free nitrogen of the atmosphere. All present signs seem to show that the fixation of atmospheric nitrogen into products of manurial value can be best brought about by the development of water powers properly and economically located and financed for the end in view.

Even if I had already formed an opinion as to the best ways and means for bringing developed water powers most rapidly into operation, I should refrain from such discussion at this time. What we engineers and chemists are most concerned with is that some compromise between widely divergent opinion should be reached to the end that there shall be more accomplishment and less conversation. Given the statistics of annual yield of our diversified crops, and also given the nitrogen content of these crops, it becomes an amusing and interesting problem to attempt to compute the annual waste of fixed nitrogen, or at least that modicum or portion of it which by export or by sewage disposal or any other of the numerous ways is discharged into the ocean or into the atmosphere, never again to return by any natural means to the fields from which it was taken away. Even under the most conservative methods of computation, the figures roll up into billows of ciphers until one gives up in despair, realizing that it is only another method of attempting to sweep out the Augean stables. And in making these statements, I am not unmindful of the fact that through green manuring and due to the action of the nitrogen-fixing bacteria which work on the roots of leguminous plants, we are furnished with at least a slow natural process for the fixation of atmospheric nitrogen. The annual wastage of fixed nitrogen from our soils is none the less appalling. It does not, however, require statistical data or complicated arithmetical calculations to convince a person with common

sense that one cannot go on forever drawing capital from the bank faster than it is put in. We owe our soils at least as much plant food as we take away from them, or agricultural bankruptcy is only a question of time. Agricultural bankruptcy spells ultimate starvation and it spells nothing else.

In 1914 we imported into the United States some 500,000 tons of Chile saltpetre at a value of about $18,000,000. It has been estimated that perhaps one-quarter of this found its way to the soil, in addition to such other forms of fixed nitrogen as ammonium sulphate from coke recovery and the various kinds of organic nitrogen, such as slaughter house and other refuse. But all this is not nearly enough. In Norway alone about 500,000 kilowatts are engaged in the manufacture of artificial saltpetre. In the United States proper it is doubtful if any artificial nitrate has as yet been produced on any scale beyond the experimental, and yet it has been computed that every cubic mile of our atmosphere contains enough raw material in the form of free nitrogen to satisfy our total present consumption for more than half a century. I know of no stronger argument than this for the immediate development of our available water powers, unless it be that these same water powers put to work on nitrogen fertilizers could, at the same time, provide the material necessary for the national defense in case of war.

I should like to take this occasion to add my voice to those of many more distinguished colleagues, in pointing out that though it may be considered desirable to develop water powers in this country, it is very important to take into consideration that such water powers should be suitably located, and that the cost of production of electrical energy should be as low as possible. This is particularly true with respect to the manufacture of artificial fertilizer. The cost of munitions matters little in the face of the emergency of war, but the cost of plant food must of necessity always be kept at a minimum. A water power that costs capital a hundred dollars or more per horse power to develop, and that must be rented for from $17.00 to $20.00 per horse power year, will never solve the problem of cheap food production. Some system for developing low-cost water power must be devised, or, as far as the food problem, is concerned, we shall never become self sustaining or nationally independent. Up to 1914 more than 80 per cent of all the mixed fertilizer produced in the United States

was used east of the Allegheny Mountains. This point is admirably illustrated in the fertilizer expenditures map taken from the Thirteenth Census of the United States, which will be discussed in a later paragraph. A developed water power in Alaska, Washington and Oregon could have no possible influence upon this condition. To be practical, electrical water power must serve its own market and its own neighborhood, or it might as well be located on the moon. The growing city populations composed of the millions who live in such great cities as Boston, New York, Philadelphia, and Baltimore, do not contribute to the production of food. With respect to food, they are consumers only, and the soil alone can feed them. It is inevitable that sooner or later the potential energies of our great water powers must be harnessed to the end that the nitrogen of the air may be fixed to feed the soils.

With respect to the necessary supplies of plant foods other than nitrogen, it has not as yet been seriously considered to utilize electric power, but, speaking to electrical engineers, I can say that the extraction of potash from feldspathic and granitic rocks by electrolysis presents by no means an insoluble or even, in my opinion, a difficult problem. It is perhaps the easiest way that has been as yet proposed to artificially obtain potash, which only awaits cheap enough power to become a reality. I need only remind you that in the silicate rocks of which our mountain ranges are composed, there lie dormant untold billions of tons of potash, to show that when the proper time comes we will not want for raw material. On this special topic I am well informed, for I have made a close study of it in the laboratory and in the field for many years.

In regard to our supplies of phosphate, Nature has been extraordinarily generous to this country, and the vast phosphate fields of the South and West are in no immediate danger of exhaustion. In order to make the phosphoric acid content in these phosphate deposits available for agriculture, it is necessary and usual to treat them with sulphuric acid in the manufacture of super-phosphates. It happens, however, that we possess very large deposits of phosphate rock which, while rich in phosphoric acid, contain also as impurities something more than 5 per cent of iron and alumina. Such phosphate deposits as these cannot be treated by the usual sulphuric acid method, owing to the fact that they show a tendency when treated with the acid to become sticky so that they cannot be ground for mixed fertilizer or be

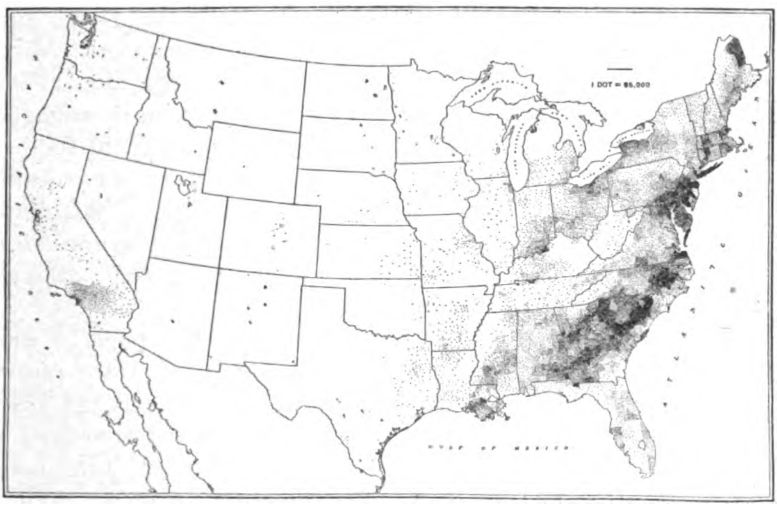
properly spread upon the soil. These high iron, " A " phosphate deposits, as they are called, are awaiting an economical process for their treatment, in order to make them available to agriculture. It is my belief that with cheap electric power, this problem can also be solved from the standpoint of electrochemistry.

I shall now present certain data taken from the thirteenth census of the United States (1910), which, in my opinion, shows the urgent necessity for the ultimate application of developed water powers to the food problem of the future. The total area of cereals harvested in 1909 was about 191,000,000 acres as compared with about 185,000,000 acres in 1899, a gain of about 3.5 per cent. During the same period the production increased only about 73,000,000 bushels or 1.7 per cent. The yield per acre was therefore slightly less in 1909 than in 1899. At the same time the population of the United States proper increased from 76 to 92 millions, or 21 per cent. These figures are significant and authoritative, although it is fair to add that they are affected to some extent by bad weather conditions in the corn belt in 1909. The magnitude of a crop is determined by acreage and yield per acre, but the latter factor is the one with really measures in the long run the efficiency of agricultural operations. The yield per acre is affected by some conditions, such as weather, that are beyond the control of man, but no one can say that by the proper use of fertilizer, other things being equal, the production per acre can not be increased many fold. This is indicated also by the fact that European acres before the war were yielding from two to three times that of our own. Leaving aside the questions of proper tillage, plant breeding, seed selection and other important factors in crop production, as not germane to the present subject, let us inquire what the country was doing in the use of plant foods on our soils.

According to the last census report, the total number of farms that reported expenditures for fertilizers in 1909 was about 1,800,000 or about 29 per cent of all farms. The total amount expended for fertilizer in 1909 was about $115,000,000, and the average amount spent per acre of improved land (based on the acreage of all farms) was 24 cents. This average is made up of variations of from one cent per acre in the West, North Central, and Mountain sections to $1.30 in the New England division and $1.23 in the South Atlantic. It is, of course, true that the differences in the expenditures for fertilizers reflect differences in natural fertility of soils, in character of crops grown, in cus-

tomary methods of agriculture, and in freight rates on commercial fertilizers from mill to market. But nevertheless the value of all crops grown in the United States in 1909 was very nearly five and one-half billion dollars, in the production of which some fifteen million dollars-worth of plant food was used, or just a trifle more than one-quarter of one per cent.

I submit that these figures speak for themselves, and that the conditions have not been materially changed in the intervening years between 1909 and 1916. What more strenuous argument is needed for the development of our water powers to the end that they shall be set to work on the production of plant food for



Distribution of Fertilizers in United States in 1909

the coming generations? Is it not indeed a duty that the present generations owe to posterity?

Before concluding, I invite your attention to the most illuminating map taken from the last United States census, which gives the expenditure by farmers and the distribution of fertilizers for 1909. This shows at a glance the truth of much that has been set forth in preceding paragraphs, and it shows much more. This map might be made the basis of a popular travelogue. If we use imagination, we can picture to our minds the strenuous drive of the Aroostook County, Maine, potato industry, the efforts of the truck growers of Massachusetts to feed the teeming millions of their congested cities and manufacturing districts. We pick out the high grade wrapper

tobacco section of Connecticut, whose product is worth dollars per pound and is found worthy of lavish expenditures for fertilizers. We see the effort to supply the New York, Philadelphia and Baltimore markets, and follow the truck gardens down the Jersey coast to the tip of the Eastern Shore of Maryland. Further south we pick up the tobacco belt and the great region where King Cotton reigns supreme, and this King is powerful to exact his annual tribute of plant food. We see the effect of fruit growing in Florida and southern California, these regions which are still too sparsely fertilized. We can see the sugar cane waving in Louisiana, and even trace the national grape juice from the serried grape vines on the southern shore of Lake Erie. We travel on through the great corn belt of Ohio and southern Illinois, until we come to the Mississippi, but here, as far as our subject goes, we stop. The great grain producing states of the Far West are busily engaged in taking money out of the bank, but, as far as plant food is concerned, they are putting little or nothing back. It is probably true that all agricultural districts appearing on this map, which do not show up in black or at least dark gray, are to a greater or less extent proceeding along a similar pathway towards the ultimate destitution of our soils.

The task of attempting to present in a brief paper a discussion of so vast a subject as the influence of water power development on the food problem of the future has not been an easy one, and I am fully conscious of the fact that only a few high points within the range of the subject have been touched. It is possible, however, that there are many people in this country who have never yet realized that the potential energy of a flowing river can be transmuted into food and sustenance, and thus indirectly direct the vital activities of a nation. The scenic grandeur of a great waterfall may be a national asset, but I am one of those who see an even greater grandeur and a more valuable national asset in vast fields of waving grain and contented, well nourished herds, which mean, as they always have and always will mean, a contented, virile and industrious population.

To be presented at the 321st Meeting of the American Institute of Electrical Engineers, Washington, D. C., April 26, 1916.

WATER POWER AND DEFENSE

BY W. R. WHITNEY

ABSTRACT OF PAPER

The United States has no adequate domestic source of fixed nitrogen. Nitric acid is an absolute necessity in the manufacture of any form of explosive as well as in the production of dye stuffs. Ammonia or nitrate compounds are in increasing demand as fertilizers. The present dependence upon Chile is a menace in case of war and involves the payment of export duties and profits amounting to nearly $5,000,000 annually in times of peace.

Home production is wholly a question of initiative and proper utilization of water power. Failure to establish the industry in the past has been due to economic conditions, such as the relative proximity of Chile and the impossibility of competing with the cheap water powers of Scandanavia as well as the lack of a near-by agricultural demand. The growing need for fertilizers, the desirability of establishing a dye-stuff industry and especially the feeling of uncertainty in international relations make a reconsideration desirable.

National safety demands the development of a nitrogen fixation industry whether it be self-supporting or not. But the industry once established the products would be of the greatest value in times of peace and many other industries would be stimulated thereby. Thorough industrial organization is the best preparedness for either peace or war.

Each of the processes under consideration have advantages. The problem is many sided and far reaching and hence it is very desirable that the various government departments concerned, those of the Army, Navy, Agriculture, and Interior, with their skilled staffs and expert knowledge should cooperate in determining the course to be taken. Immediate action is very important since at least two years will be consumed in getting any process available into operation, after a decision is reached.

VIEWS on the relationship between our water power problems and the problems of national defense are as different as they are numerous. No one is safe in assuming that he has, for long, held the correct view, for the correct view changes rapidly with the conditions, and these changing conditions are not entirely under control. There are a few facts which it may be wise to review because of the changing conditions referred to, and because all of us are interested in national welfare.

A group of these facts which relate to what we call fixed

Manuscript of this paper was received April 14, 1916.

nitrogen should be foremost in our interest. They may be briefly stated as follows. The United States has thus far practically no natural sources of niter or other form of fixed nitrogen, nor has it developed any sources of the artificial products beyond the recovery of ammonia from gas-liquors and coke ovens.

Niter has always been the *sine qua non* of explosives, and with all the complicated developments which have taken place in the field of explosive manufacture, nothing practical has been produced which does not depend absolutely upon niter.

The old type black gunpowder which contained niter, sulphur and charcoal, used the salt as such. The later smokeless powders made use of the nitric acid produced from niter by means of sulphuric acid. The cellulose, the glycerine, and the toluol in gun cotton, nitroglycerine and trinitrotoluol respectively, are wonderful substitutes for the sulphur and charcoal of the former explosives, but what we may call the pepper in the powder has always been the nitro group from the niter.

This means, to those who are considering the question of preparedness for defense, that our sources of niter need a lot of insurance. It is not at all inconceivable that our present available supply of niter in South America might become closed to us in the event of war.

The problem of a home source of niter is an old one in the United States. The material has long been used by our fertilizer industries. Organizations representing agricultural interests have tried to bring about reduction in cost of fertilizer necessities —phosphate, potash, and nitrate or ammonia. We have plenty of phosphate rock in the United States, so that freight rates will apparently be the determining factor on the extent of use of this fertilizer ingredient. In the case of potash we are in bad shape. We have some unlocked sources, but nothing comparable with the German supply. We must learn how to cheaply separate potash from our feldspars, our seaweeds, or our ocean waters, and there seems little chance that this will be economically done very soon.

But when it comes to nitrate and ammonia, it is distinctly up to us. The cost will depend on the way in which we use our water power. The raw materials come from the air and the water, and ought to be free to us. At present we are subsidizing the Chilean government at the rate of $2.25 per ton, or nearly one and one-half million dollars a year for export duty, besides paying a profit of five to ten dollars per ton to the producers. This amounts to, say, five million dollars annually.

In addition to our fertilizer interests, the country has become greatly interested in the aniline dye and chemical industry question. No single chemical is so generally important to this industry as nitric acid, and with us it is all obtained from niter. This fact seems to be an additional reason for attempting to round up our local needs for fixed nitrogen, determine the advisable steps to take, and quickly take them.

It is practically true that the aniline dye industry is essential to the manufacture of modern explosives. The identical materials which are developed for dyes, now constitute the basic ingredients of the picric acid, trinitrotoluol, and tetra nitro methyl aniline used in the present war. The coal tar products, the acids and the apparatus are common to both dyes and explosives. For this reason, if we are to be efficient, if we are to have plants capable of producing explosives in large quantities when needed then those plants must be producing useful chemical and dye products in times of peace.

If it were only necessary to dam the small water courses and pump the air through some sort of simple apparatus, in order to get niter more cheaply, the work would be easy. The question is in reality very complicated. It has never seemed worth while to dam the water ways to make niter in this country. In the first place, our farms, except in certain long tilled or special ocalities, have not fallen so low in productivity that it pays the farmers to meet the prevailing costs of artificial fertilizer. This condition is a continually changing one, and it is always changing in the one direction. We shall as surely have to come to the extensive use of artificial fertilizer as have all the older countries. Our western grain and corn states are now producing only about half as much per acre as are the eastern states, and the difference is in fertilization.

Secondly, we have been able thus far to procure Chilean niter for our limited explosive and chemical manufacture while the processes for obtaining nitrogen compounds from the air have been in a state of flux or development. It was a peaceful world-economy which established the first practically operative and successful nitrate plant in Scandinavia. There such plants are close to the cheapest water powers, remote from all other sources of nitrate, and near the best markets. Norway's water powers differ essentially from our own. Nowhere in the United States not even at Niagara, are there existing grouped conditions such as could compete successfully for cost of power with Norway.

This is not generally remembered, but to engineers it should be plain. In Norway there was the fortunate combination of exceedingly elevated water level, of quite dependable and high rate of uninterrupted flow, with immediate ocean shipping facilities and a world's hemisphere of well established market close at hand. An expensive dam, or any dam at all was frequently unnecessary. Building sites were probably donated. Fertilizers were most extensively used and most of the world's chemicals and dye stuffs were made in the adjacent countries. Under such conditions there was apparently no reason for our country's doing this work, and that is why it has not been done.

It is the new conditions which make reconsideration worth while. One of these new conditions is our recently acquired feeling of uncertainty as to the permanence of peace. Another is our growing need for fertilizers, and a third, our desire to insure our textile industries by producing our own dyes and chemicals. Probably every human being on the earth today who has reflected at all, has been astounded at changes which a few months have produced in the most civilized countries of the world. It is not surprising that some of us should look about more or less nervously to see if our powder is all right.

Judging by past events, I think we are justified in imagining conditions which might effectively interfere with our continued supply of Chilean niter. Difficulties might arise before the salt is mined, as was the case with potash in Germany before the war. Transportation troubles from interference on the ocean, or trouble in Panama might be effective in shutting off our supplies. Perhaps the danger is slight, but if our importations of niter should cease, then all our efforts at dye stuff manufacture would fail, and all our efforts at national defense, beginning with diplomacy and ending with torpedoes, would be as useless as a poem on Spring. If we cannot shoot a gun, explode a mine or fire a torpedo without nitrate, we ought to be sure of our nitrate before we are forced into war. We need powder before we need soldiers or guns. Evidently this is a matter for mature deliberation on the part of those best fitted to weigh the possibilities.

Our requirements seem to suggest some early and effective type of cooperation between the department of the Interior, the Agricultural Department, the Army and the Navy, which departments are most intimately interested and best equipped to form opinions on the separate parts of this subject.

It is not my intention to consider the different ways of making

nitrates, but a few words will show how rapidly the industry has recently advanced.

Since the experiments of Bradley and Lovejoy at Niagara, the Birkeland-Eyde electrical process has come into extensive commercial use in Norway. The Schonherr process, another arc process, has been developed in Germany, and the Pauling process in Austria. The cyanamid and Haber processes for ammonia combined with some form of the Ostwald process for changing ammonia to nitric acid, have both contributed to Germany's nitrate needs. The cyanamid process, using electrical power for making the calcium carbide, which is later employed for chemically combining the nitrogen of the air, was said in 1914 to be represented by 14 different plants, representing an investment of $30,000,000. Since the beginning of the war, this process has been greatly agumented, apparently beyond any other. At the present time, Germany is probably using artificial nitrates exclusively, and the allies are beginning to employ them to a lesser extent.

It is because no group of our national representatives are likely to know all aspects of the nitrogen fixation problem, that the assistance of different interests and departments seems worth acquiring. It seems certain that our demand for nitrates for use in fertilizers, in heavy chemicals, pharmaceuticals, and dyes in time of peace, together with our possible needs for ammunition in times of war, would justify radical steps which any one of these apparent demands, taken alone, might not warrant. It is also probable that if our peace needs were properly taken care of, our war needs would be assured by the identical plants and processes.

It has been suggested that in an emergency, our electric street car and city lighting plants could quickly be turned into nitrate producers. A suggestion of this sort should be analyzed for our government by those competent to judge of the possibilities, and not be left to analysis by a pitiless fate.

It may be worth while to offer an opinion on a few of the questions naturally asked nowadays by the engineer concerning the possibilities of nitrate production in the United States. In times of peace and with present synthetic processes, commercial success is not possible if the electrical power costs are as high as fifteen dollars per kilowatt-year, and there are no profitable by-products. At about half of this rate one or more of the present processes might possibly compete with the natural anti-bellum

prices. This could not be done by the use of small isolated plants, nor less than full day load of power. In other words, it would not attract those who ordinarily sell electric power.

This is not the nations' question, however. It is more a question of whether, in times of dire necessity, we could at some inconvenience and high cost, effectively produce within a reasonable time our own requirements of niter. Could a part of existing electrical equipment be quickly utilized for this purpose? Under such conditions would a part-day load be permissible? Could coal be used for power? I do not answer as an expert, but I think that we may safely say that it would take us a couple of years to get under way with the manufacture on any appreciable scale after the delays which would certainly be connected with our decision to start, were passed. The cost might not be relatively greater than are the increased costs of many other products during war time. Electrical equipment already installed might in some cases be employed, but in all probability this would be called upon for other uses with greater advantage to the country. As most of our industrial plants would have to do what they could best do, it seems probable that entirely new plants for nitrate would be called for. I believe this has been the experience abroad. In any of the synthetic processes, extensive and special types of apparatus are necessary. special transformers, special combustion chambers, large capacity air-liquefiers, etc. In the absence of water power such a plant could operate on steam power, but should be placed as near as possible to a coal supply. The possibility of utilizing waste coal, if there is any such thing nowadays, is worth looking into in connection with this question. It does not seem probable that part-time load is practicable even in war time, for the production of nitrate. By the arc process, something like three kilowatt-years may produce a ton of nitric acid, but when the demand amounts to two or three hundred thousand tons of acid per year under war conditions, and requires in that case the twenty-four-hour continual operation of over half a million kilowatts, the impracticability of getting any appreciable proportion of it from the off-peak power of present plants seems apparent. It is only fair to note that one of the processes is said to produce the acid at nearly a sixth of this consumption power. But in this case, the operation in conjunction with existing power plants seems still less possible on account of the nature of the process.

Nowadays the essentials of national preparedness seem to

require longer periods for accomplishment than formerly. When it takes years to build a battleship, war is not a brief siege. The art of successful defense has become a slow and subtle one. It starts with the high school and the education of children. It gets its main strength from the masterly control of technical industries. It owes its effectiveness to novelties in ways of killing, and its staying powers to business foresight and discreet banking policies. It has been well said in this connection that "there is one line of action which we ought to begin at once, and that is, we should begin at the bottom and prepare our industries."

It has also been pointed out that, strangely enough, many of the most useful modern chemical requirements of war are also the leading chemical products of the industries of peace. The chemist sees that sulphuric and nitric acids, chlorin, caustic soda, gasoline, benzol, phenol and toluol, perhaps the most industrial of the compounds in peace, are also the most extensively required in modern war. Similarly, the engineer knows that the modern air hardening tool steels, the modern lathes, the newest boring mills which industrial advance has developed, are now the necessities of munition production. So that industrial activity is a healthy type of national preparedness for both peace and defense.

But for national preparedness, our industrial activities should be comprehensive and cooperative. Whole fields of national interests should not be left entirely untouched because some other country is already profiting in them, as in the case of nitrates today. When it comes to national defense, we must ask ourselves what necessary supplies may be cut off by war? It is for this reason that England, Australia, Canada and Japan have already established national research organizations.

Preparing for defense is consistent with keeping at work in a proper way along the lines of peaceful, healthy industry. In this way it bears on the subject of waterpower. The engineer will always have the feeling that the power of falling water is a continuing loss excepting when it is doing useful work. This is inseparably connected with his first lessons in mechanics and thermodynamics, and is probably right. If a single manufacturing company owned our farms and water ways, it is probable that for reasons of efficiency it would make all the available falling water do the work needed to maintain the fertility of the soil or produce useful products. This would only be doing in a broader way what the potentates of Egypt and Assyria had to do cen-

turies ago, when their irrigating systems were built. But we live under a representative form of government, where the difficulties and delay of getting constructive activity are what it costs us to be democratic.

At least two great processes for fixation of nitrogen have been offered to our government in the past few weeks. I refer to the arc process of the du Pont Company and the cyanamid process of the Cyanamid Company. These are essentially different. No brief discussion can bring out their relative values to our country. I consider both of them of the greatest importance to us.

The duPont process, yielding nitric acid directly from the air, calls for cheap water power. Used in conjunction with the production of explosives and the manufacture of chemicals and dye stuffs, it would be a great boon to America in times of peace, and invaluable in war time. The enormous facilities of such a company, widely interested in large scale chemical production and with one of the largest experimenting organizations in America, would certainly bring the arc process much nearer to that high condition of efficiency which the theory of the process predicts and which sometime will be realized somewhere—I hope in America. There is every reason to expect that there would result the evolution of as many new and useful products and processes as are being continually produced in Europe. Several hundred thousand kilowatts are now employed by the arc processes abroad.

The cyanamid process also calls for cheap waterpower and in large quantity. This process seems, at the present stage of things, to be of the greatest importance to our fertilizer industry because of its economical production of ammonia, the form of fixed nitrogen commonly used in commercial fertilizers. The manufacture of nitric acid and ammonium nitrate for explosives by this process is apparently easy and would be economical at power costs which we ought easily to reach in this country.

It is stated that there were somewhat over 200,000 h.p used by the cyanamid process abroad in 1914, and in the past eighteen months Germany has invested $100,000,000. in this work.

These are both tested processes, and we are interested in their present, and even more particularly in their future developments. In any undertaking by our government which involves the granting of special water power rights, the people should want foresight coupled with active, constructive work. It seems as though we might fairly expect sometime a change in the public spirit,

which now usually views almost any large manufacturing undertaking with animosity and adverse criticism. Possibly through the study of these immediately pressing problems of explosives, dyes and fertilizers by our most competent and interested government experts, sound business criteria may be established for the nation's benefit.

Personally, I have a fear that we are forever shortsighted. I am afraid of the need for national defense which may come upon us like a thief in the night, from war declared in a day, because I fear that impotency which is spread over a century and never really discovered until too late. The most imperilled country of the present war is learning more about national defense than we are at present, and is not likely to forget the lessons. New industrial processes will continue to be improved by those people who are now actively engaged in them. The more extended become the details, by-products, contingent interests and economies in any such line of industry, the more difficult becomes the start in it by an outsider. It is not out of the question that ten years form now the commercial sources of nitrate will be Germany and Chili. The artificial processes will certainly be improved. The natural source will about as certainly deteriorate. What will we be doing in the meantime? It may be entirely safe to depend indefinitely on Chilean supply, but the question should be decided for our country by those who are responsible and will give it careful consideration.

I believe effective good could be accomplished by quick cooperation between those different government departments where lie the greatest direct interest and knowledge. One of these is the Department of the Interior, under which come the group of experts of the Bureau of Standards and the Bureau of Mines. These certainly possess men interested in industrial chemistry, well equipped, and anxious to serve. The Bureau of Soils of the Department of Agriculture has also a corps of men equally well fitted for this work, and particularly interested to that part of it referring to the fertilizer problems. The Army and Navy Departments, busied with the multitude of normal duties of defense, might still lend a great deal of aid and pressure to this cooperative problem, without having to produce the same kind of chemical and engineering experts found in the other departments. The country ought to be satisfied with the joint conclusions of such representatives of its interests.

To be presented at the 321st Meeting of the American Institute of Electrical Engineers, Washington, D. C., April 26, 1916.

RELATION OF WATER POWER TO TRANSPORTATION

BY LEWIS B. STILLWELL

ABSTRACT OF PAPER

The paper discusses the relative importance of water power in its relation to transportation, as depending upon its cost and the cost of competing steam power.

Proportion which "Cost of Fuel for Locomotives" in the country as a whole, in various sections, and in the case of a number of different railroads, bears to "Total Cost of Operation."

Effect of recent progress in art of producing electric power by steam upon water power values.

Power and transportation development on navigable streams.

Illustrations of the limit of investment in developing a water power, as fixed by cost of competing steam power.

Comparative cost of canals and railroads.

Illustrations of comparative speed and power consumption in railroad and canal operation.

THE RELATION of water power to transportation in the United States is a subject far too broad, and in some of its aspects too complex, for comprehensive and adequate treatment in a twenty-minute paper. Like many other subjects with which engineering science deals, the economic factors which determine that relation in any given case depend so largely upon local conditions as to make useful generalization difficult, if not impossible. The best that I can hope to do in the time allotted for this introduction to your discussion of the subject is to point out some of the conditions which determine the value of water power in relation to transportation at the present time, and to indicate roughly how this value may change with progress of the art of producing power from fuel and with changes that may occur in the interest rates upon capital necessary to development.

The relative importance of water power used as motive power to move traffic, in its relation to transportation, in different parts of the country varies, depending primarily upon the cost of water power and the cost of competing steam power as developed by locomotives or by existing or possible steam power plants. Where water power is produced, or may be produced,

anuscript of this paper was received April 14, 1916.

by building dams on navigable streams, the production and possible utilization of power are interrelated with the problem of inland waterway transportation, owing to the fact that the construction of a dam may be made to serve the double purpose of developing the power and creating a stretch of navigable water.

Cost of Fuel for Locomotives

The following interesting statistics giving for the Eastern, Southern and Western Railroad Districts, and for All Roads, the "Miles of line operated," the "Cost of fuel for locomotives," the "Total operating expense," and the "Ratio of fuel cost to total operating expense," are taken from the report of the Interstate Commerce Commission for the year ending June 30, 1914:

FUEL FOR LOCOMOTIVES, AND TOTAL OPERATING EXPENSES, FOR ALL RAILROADS IN UNITED STATES HAVING OPERATING REVENUES GREATER THAN $100,000 IN THE YEAR.

	Eastern district	Southern district	Western district	All railroads
Miles of line operated	62,780	46,587	136,257	245,624
Cost of fuel for locomotives	$ 104,461,133	$ 33,052,970	$105,286,696	242,800,799
Total operating expense	1,004,620,282	348,295,136	847,397,741	2,200,313,159
Ratio of fuel cost to total operating expense	10.45%	9.50%	12.40%	11.05%

It will be noted that the "ratio of fuel cost to total operating expense" varies from 9.50 per cent in the Southern District to 12.40 per cent in the Western District, the grand average for all railroads being 11.05 per cent. The total expenditure for fuel for the year is $243,000,000.

Obviously, any substantial reduction in cost of fuel would mean an important saving in total operating expense of our railroads. For example, were it possible, in the case of the average railroad, by using water power to effect an economy equivalent to a reduction of 50 per cent in the fuel bill, a reduction of about 5½ per cent of the total operating expense would result; but unfortunately water power can be substituted for coal or other fuel in the operation of railroads only at the price of an investment in hydroelectric machinery, in transmitting and distributing conductors, and in electric locomotives, so great that a saving of 50 per cent in the fuel bill would constitute in itself

an economy by no means sufficient to offset the increase in interest charges upon the investment necessary for electrification. The bearing which such a possible saving would have upon the question of electrifying what may be termed the "average" railroad is shown by the following figures, which are abstracted from a paper "On the Substitution of the Electric Motor for the Steam Locomotive," presented by the writer and H. St. Clair Putnam at the 214th meeting of this Institute. While these figures were prepared nearly ten years ago, additional operating data of electrified railroads now available are corroborative of their general correctness and they are sufficiently accurate for our present purpose. The figures compared are, first, the average for steam operation during five years, from 1901 to 1905, inclusive, as reported by the Interstate Commerce Commission, and, second, the cost of operation by electricity as estimated in the paper referred to.

	Average five years	Estimated cost of operation by electricity
54. Maintenance of way and structures	21.003	22.354
55. Maintenance of equipment	19.524	12.587
21. Engine and round house men	9.451	4.710
22. Fuel for locomotives	11.292	5.702
23. Water supply for locomotives	0.634	.000
24. Oil, tallow and waste for locomotives	0.381	0.250
27. Train supplies and expenses	1.537	1.000
29. Telegraph expenses	1.780	2.000
35. Loss and damage	1.112	0.750
36. Injuries to persons	1.086	1.000
37. Clearing wrecks	0.246	0.200
	68.046	50.553

(The above items are numbered as in the report of the Interstate Commerce Commission, and only items the amount of which is changed by electrification are included.)

The total estimated saving in cost of operation is approximately 18 per cent of this amount, a saving of one-half in fuel accounts, in round numbers, for approximately one-third of the total saving. Reduction in fuel expense which may be effected by utilizing water power, therefore, under average conditions will affect practically but one-third of the total savings due to electrification upon which the question of substitution of electric power for steam will depend in the case of a railroad which may find itself in position to secure the capital necessary to electrify a part of its system.

The following tabulation from the report of the Interstate Commerce Commission for 1914, shows, as might be expected, that the relation which the cost of fuel bears to total operating expense of different railroads varies between wide limits:

STATISTICS FROM I. C. C. REPORT ON RAILROADS, FOR YEAR ENDING JUNE 30, 1914.

Road	Approx. thousands miles of line operated	Cost of fuel for road locomotives millions	Total oper. exp. millions	Ratio fuel for rd. loco. ÷ total oper. exp.	Average tons freight per train	
					(1910)	(1914)
A. T. & S. F.	12.4	5.6	60	9.4	298	357
A. C. L.	6.0	2.6	26	10.0	201	225
B. & O.	8.9	5.6	72	7.8	443	620
C. & N. W.	12.7	6.0	59	10.2	261	348
C. B. & Q.	13.1	5.8	62	9.4	381	479
C. M. & S. P.	14.3	7.75	61	12.7	276	380
D. & H.	1.9	1.9	15	12.7	428	532
D. L. & W.	2.6	2.4	26	9.2	545	652
Erie	4.6	3.2	37	8.7	497	593
Gt. Nor	10.1	5.3	46.5	11.4	520	663
Ill. Cen.	7.7	3.8	51	7.5	364	417
L. V. R. R.	3.4	3.1	28	11.0	536	588
Mo. Pac.	5.0	2.0	22	9.1	240	329
N. Y. C.	9.4	7.0	86	8.2	413	503
N.Y., N. H. & H.	4.6	4.5	49	9.2	293	304
Nor. & West.	3.8	2.9	30	9.7	635	802
No. Pac.	9.7	5.0	41	12.2	429	567
P. R. R.	10.5	9.3	134	6.9	649	729
Reading	2.8	3.2	32	10.0	477	580
Southern	9.8	3.8	50	7.6	237	275
So. Pac.	9.5	4.9	55	8.9	428	431
U. P.	5.7	3.7	29	12.8	432	431
Wabash	4.2	2.3	24	9.6	353	393
	172.7	101.65	1095.5	Av. =9.3%		
All R. R's. in U. S.	245.6	208.4	2200	Av. =9.5%		

It will be noted from this and from the preceding summarized tabulation that fuel cost in general is high upon railroads operating between the Mississippi River and the Pacific Coast, coal being less generally available at moderate cost in this territory than in other parts of the country. For example, while fuel for road locomotives in the case of the Pennsylvania Railroad represents 6.9 per cent of total operating expense, and in the case of the Illinois Central 7.5 per cent, it amounts to 12.8 per cent in the case of the Union Pacific and 12.7 per cent in the case of the Chicago, Milwaukee & St. Paul. While many factors other

than the cost of fuel per thermal unit affect these percentages, no argument is required to demonstrate that the cost of coal is a very important factor in railroad operation, and that any important reduction in this cost means increased net earnings, decreased cost to shippers, or both.

It is a fortunate fact, which frequently has been pointed out, that in certain very important sections of our country where coal deposits are lacking, water power is abundant, and since the cost of competing steam power primarily determines the relative value of water power, it follows that the water powers on the public domain, in general, have a relatively higher potential value than they otherwise would possess, owing to the fact that they exist in localities where coal or oil, or both, are relatively expensive. Further, it is to be noted that these water powers are naturally found in hilly or mountainous sections through which the operation of railroads implies the handicap of grades, in many instances heavy, and consequently the consumption of power at a relatively high rate per ton-mile. Broadly speaking, therefore, these mountain water powers in sections where no deposits of fuel exist are of especial interest and possible value in relation to transportation.

The question whether it would pay to substitute electricity for steam as motive power on a given road, or a given division thereof, or even on a certain mountain grade, can be answered only by exhaustive and competent consideration of many factors, among which the cost of power, while an important one, is not necessarily controlling. It is impracticable, therefore, to attempt to fix with precision as a general case the limit of allowable investment in water power development within which a saving for electrification would be shown, as compared to operation by steam.

It may be pointed out, further, that where cheap water power is available in connection with transportation in a hilly or mountainous country, the conditions which control the extension of a railroad system are affected by the fact that cheap electric power makes it practicable to adopt grades exceeding the limits which experience has established in steam practise. The resulting possibility of shortening lines and reducing the cost of the permanent way construction may be important in new territory, although it must be noted in this connection, also, that as regards new lines in such territory over which traffic for a time is usually light, the investment in hydroelectric plant and in rail-

way electrification is generally greatly in excess of the cost of locomotives.

No consideration of the problem of electrifying a railroad, or a division, or a mountain grade, is complete which fails to take into account the fact that the cost of competing steam power has been decreased materially in recent years by improvements in the design and efficiency of the steam locomotive, or to recognize the probability that further improvements will result from the continued efforts of the many able men who are devoting their energies to advance in locomotive design, with special reference to fuel economy; nor is any consideration of the relation of water power to the operation of a railroad complete which omits consideration of the great reduction in the cost of electric power produced by steam-driven generators which has been achieved within the last fifteen years by the substitution of the steam turbine for the reciprocating engine and by improvements in boiler construction and practise. For example, a 5000-kw. turbine-driven alternator today, at its point of best efficiency, will produce a kilowatt-hour using 20 per cent less coal than was required fifteen years ago by the 5000-kw. units which the Manhattan Elevated Railway of New York installed at its Seventy-fourth Street power house, these latter being at least equal in efficiency to any engine-driven units installed in this country up to that time. Moreover, this reduction in cost has been characterized not only by a reduction in the amount of fuel required to produce a kilowatt-hour, but also by a relatively still greater reduction in cost of plant, as illustrated by the fact that a 5000-kw. turbine-driven unit today costs about $12.00 per kilowatt, while the cost of the engine-driven units to which I have referred was $35.60 per kilowatt.

Still further, the development of the dynamo in large and still larger units in connection with the evolution of the modern steam turbine makes it practicable today to realize still greater economy both in first cost and in fuel consumption, owing to the fact that we now can avail ourselves of larger units than were formerly on the market. This additional gain is particularly marked as regards fuel economy. It is probably conservative to say that a large plant, *e.g.*, one of 100,000-kw. output, using large steam turbines, in producing electric power to meet average conditions of demand as existing in our large cities, or in railway service, will use not more than two pounds of coal where the best steam practise fifteen years ago would have required three pounds.

As in the case of stationary steam plants, so also in the case of steam locomotives substantial progress in fuel economy has been made in recent years, and still further progress in this direction must be anticipated and taken into consideration in connection with future utilization of water powers aiming, in whole or in part, to supply electric power for railroad operation.

Power and Transportation Development on Navigable Streams

The relation of cheap power and waterways, as simultaneously developed by the construction of dams on so-called "navigable" streams, is a subject so complex that I can glance at it only in certain aspects. By constructing a dam at a suitable location on almost any stream of reasonable magnitude, a certain amount of power will be produced and a stretch of navigable water of more or less length developed. What the commercial value of the power thus produced will be depends primarily upon the cost of competing steam power as it is produced, or might be produced, in the same locality, and upon the demand for power for industrial and other purposes. What the value of the resulting stretch of slack water may be for purposes of navigation will depend upon so many varying conditions that profitable generalization is practically out of the question. Each project of this kind should receive the most careful consideration, not only from the standpoint of technical engineering, but also from a broad economic standpoint. No conclusion which points to the investment of an amount of capital in excess of that which would suffice to produce an equivalent result as regards the production of power, the provision of transport facilities, or both, can be sound. Railway rates being now subject to regulation by the Interstate Commerce Commission, the argument that the construction of a waterway possesses an economic value to the community in its effect upon railway rates, loses whatever force it may have possessed before a proper method of protecting the shipper was available. To expend public or private money in constructing waterways for such a purpose is to waste a part of that very accumulation of capital by the nation upon which further development of our resources in transportation, in power, and consequently in practically every form of industry must depend.

As regards power production, investigation of every project aiming to accomplish the double purpose of producing power

and providing transportation facilities, should have reference primarily to the cost of competing power produced from coal or other fuel. As regards the utility of any navigable inland waterway which may result from the construction of a dam, it should have reference primarily to the cost and relative advantages, not only of existing railroad facilities, but of new railroad facilities which the investment of equivalent capital might provide. The fact that it has been the policy of the Federal Government to appropriate public money, from time to time, for the development of waterways serving communities more or less local, and that it has not been the policy of the Government to use public money for the construction of railroads, need not and should not influence the investigation of such a project from an economic standpoint. All investment of capital, whether by the Government or by individuals, which results in accomplishing at a great expense a purpose which can equally be attained at less expense, is a waste of capital, which inevitably implies a loss to the community.

Looking at the project, first, as a power proposition, let us determine approximately the amount of investment in the proposed hydro-electric development, including the dam, which may be justified with reference to the cost of competing steam power. For illustration, we may assume that the water power which will result in the construction of the dam is capable of producing, through utilization of modern hydroelectric machinery, a continuous power output of 50,000 kw. A steam plant to deliver this output might comprise five 12,500-kw. units—one of these constituting a reserve to insure continuity of service. Detailed estimates of the cost of such a plant total $3,185,000, which is equivalent to $63.70 per kilowatt, exclusive of the reserve unit. This figure will cover a plant designed and constructed for permanency and for low production cost. Assuming that the available market is such that the annual load factor will be 50 per cent the output of the plant, when fully loaded, will be 219,000,000 kilowatt-hours, and its coal consumption—assuming bituminous coal of 14,000 B.t.u. per pound—will approximate 200,000 tons per annum. Allowing 12 per cent to cover interest, amortization and taxes, the total annual cost of operating the plant and the cost per kilowatt-hour will be approximately as shown in the following table, depending upon the price of coal.

Price of coal per ton	$1.	$2.	$3.	$4.	$5.
Interest depreciation and taxes at 12 per cent	$382,200	382,200	382,200	$382,200	$382,200
Operating labor and material	175,000	175,000	175,000	175,000	175,000
Annual costs, excluding coal	$557,200	557,200	557,200	557,200	557,200
200,000 tons coal	200,000	400,000	600,000	800,000	1,000,000
Total annual costs	$757,200	$957,200	$1,157,200	$1,357,200	$1,557,200
Cost per kw-hr. 50 per cent load factor	0.35c.	0.44c.	0.53c.	0.62c.	0.71c.

From the standpoint of power production, we may now determine the approximate limit of investment in the proposed hydroelectric plant, including the dam and its appurtenances. It may be assumed that annual operation and maintenance will be $1.00 per kilowatt. The permissible investment will depend directly upon the percentage assumed for capital charges, including interest, taxes and amortization. If the required capital can be secured from investors who are content to accept 6 per cent, the total capital charges will approximate 9 per cent. If it must be obtained from investors who have other opportunities for investment where they will not only receive interest on their investment but also will have a chance to double their money (and what industrial or commercial enterprise can be financed by private capital which does not offer this apparent opportunity?) we must assume capital charges at 15 per cent.

The first cost per kilowatt of maximum hour output equals $\frac{\text{Cents per kw-hr.} \times 4380 - 100}{\text{Capital charges \% of first cost}}$, and the limit of investment theoretically permissible if capital charges are taken, respectively, at (a) 9 per cent, (b) 12 per cent, (c) 15 per cent, is as follows:

Coal at	$1.	$2.	$3.	$4.	$5.
(a) Cost per kw., 9 per cent cap. charges	$157	$201	$245	$289	$333
(b) Cost per kw., 12 per cent cap. charges	118	151	184	217	249
(c) Cost per kw., 15 per cent cap. charges	94	121	147	173	199

The above table, upon the premises assumed, leads to the conclusion, for example, that in a case where coal costs $3.00 per ton and capital can be secured upon terms which make total capital charges 15 per cent per annum, an investment of $147.00 per kilowatt is justified.

Before accepting this or other conclusions from the table, however, it is highly important that the fundamental assumption upon which these figures rest, namely, that the flow of the stream is such that the assumed amount of power (in this case 50,000 kilowatts) will be surely available at all times throughout each and every year, should be verified. The vital importance of this factor, which not many years ago was too lightly considered by some engineers who made themselves responsible for large investments in this field, is now well understood. The failure to establish with certainty in advance of construction the minimum limit of flow has disappointed many expectations and in numerous instances resulted in very serious financial loss. Where water fails, coal must be used, and, obviously, to insure continuity of service a steam plant must be constructed and at times operated to make good the deficit of hydraulic power, even though this deficit should occur during but one year in twenty or fifty years. This means duplicating investment in power plant, and the real value of the water power must be estimated upon a totally different basis.

As illustrating what happens in such cases, let us suppose that, in case of the possible development which we have been considering, the variation in stream flow is such that in an exceptionally dry year, for a short period—perhaps only a few days—water is so low that practically no electric power can be developed. If this possible contingency must be faced, the steam plant must be constructed if it is proposed to supply a power market requiring continuous service, and the permissible economic limit of investment in the water power development is measured by the capitalized value of the saving which would result from using water power as a substitute for steam power when and to such extent as the water might be available. The investment in the steam plant having been made, the possible saving by substituting the water power when available is practically limited to a saving in coal and labor, but it is obvious that the cost of the steam plant, which we have taken to be about **$64.00** per kilowatt, must be deducted from the investment which would be permissible if the water power were absolutely continuous and reliable. It is evident, also, that a further sum, representing the capitalized value of the standby charges of the steam plant and of its operating charges while in use, must be deducted from the estimated permissible investment.

If we except the Niagara and the St. Lawrence, there is perhaps

no river in the United States the potential value of which as a producer of power is not radically affected by an occasional period of very low water. In the great majority of power developments on such streams it will be necessary to provide and utilize steam power as an auxiliary. Conditions under which this necessity has developed in practise, and will continue to develop as new projects are undertaken, are so varied that it is impracticable in a short paper to attempt a comprehensive discussion of the economic limitations of the problem. For our present purpose the foregoing illustrations of the limit of investment theoretically practicable where capital is available, as fixed by cost of competing steam power, and the general effect upon that limit of any reduction in the amount of water power continuously available, are perhaps sufficient.

It is an interesting fact, sometimes overlooked, that the reductions in cost of steam power which in recent years has resulted from decreased cost and increased fuel economy of steam plants, has reduced very considerably the limits of investments in water powers which, theoretically at least, were permissible, say fifteen years ago. Within that period the cost of high-grade steam plants of large size has been reduced about $25.00 per kilowatt. The amount of coal required to produce a kilowatt-hour has been decreased approximately one-third, and the capitalized value of this saving is a further amount which must be deducted from the investment permissible in developing a water power.

As regards the stretch of navigable water immediately above the dam and resulting from its construction, it is obvious that the value of this depends upon its relation to navigable water above it and below. In connection with the construction of the dam, it is usually practicable to build locks of any required size.

It is not necessary to point out to members of this Institute the fact that no conceivable general system of inland water transportation could parallel the railroads of this country and perform equivalent service. Whatever the policy of our railroads may have been in the past in regard to stifling competition by boats operating on inland waterways, the controlling and fundamental reasons for the abandonment of approximately twenty-five hundred miles of canals, constructed during the first half of the last century by States or by corporations, are to be found not in that policy, but in the fact that the invention

and development of the steam locomotive made it possible to build railroads which, constructed at less cost per mile, could operate throughout the year, could transport traffic between two given points in a fraction of the time required by the canal, and at comparatively little expense could provide terminal facilities, practically bringing the railroad to the door of the factory and capable of easy extension to meet the shifting requirements of our growing communities.

Canals vary between such wide limits, as regards width, depth, and topography of the country through which they have been constructed, that averages must be used with caution, but it is interesting to note that, exclusive of the Panama Canal, the aggregate length of canals built by the United States Government up to the present time is something less than 1400 miles, the average cost per mile being approximately $80,000.

We may compare with this figure the average reproduction cost per mile of single-track railroad, as fixed by State commission in Minnesota, Michigan and Wisconsin, in 1907, 1900 and 1903, respectively. The reproduction cost as fixed by the Minnesota commission is $44,888; as fixed by the Michigan commission, $26,138, and as fixed by the Wisconsin commission, $30,910. The highest of these, as will be noted is a little more than half the cost of the average canal (exclusive of the Panama Canal) hitherto constructed by the United States Government, while the average of the three appraisals is about $35,000. On this basis a double track railroad would cost approximately $60,000 per mile.

As regards comparative speed and power consumption in operating by electric power, on the one hand, a canal using 100-ton barges, and, on the other, a railroad, it may be interesting to compare canal operation, using electric power, with results attained on the electrified portion of the New York, New Haven & Hartford Railroad.

The following data are abstracted from a paper by Mr. H. S. Putnam and the writer, presented at the 226th meeting of this Institute, March, 1908, and relate to the canal of The Lehigh Coal & Navigation Company, extending from Coalport to Bristol in the State of Pennsylvania:

Length, L. C. & N. Company's Canal, Coalport to Bristol, 106.2 miles.
Total number of locks: Lehigh Canal, 48; Delaware Canal, 22; Total 70.
Size of Barge used in test: length 87 ft. 6 in.; width 10 ft. 5 in.; draft 5 ft. 2.2 in.

Weight of barge (tons of 2000 lbs.): empty 23.8 tons; load 113.2 tons; total 137 tons.

Watt-hours per total ton-mile, 4-boat tows, about 23 watt-hours.

Watt-hours per freight ton-mile, 4-boat tows, about 33 watt-hours.

Traffic capacity of canal, if all existing locks changed to 4-boat locks: 40 minutes interval between 4-boat tows = 72 boats in 12-hour day, or maximum total tonnage of 72 × 113.2 = 8150 tons freight in 12 hours.

Maximum speed between locks, 4-boat tows: loaded, 3 mi. per hr.; empty, 4 mi. per hr.

Time for trip of 106 miles, about 85 hours down, loaded = 1.25 mi. per hr. average; about 75 hours back, empty = 1.42 mi. per hr. average.

The watt-hours per ton-mile were determined by test, the company having equipped several miles of its canal with an electric haulage system, with a view to determining the advisability of substituting electric power for mules. It will be noted that the energy required per ton-mile, using four-boat tows,—the average load of the barges being 113.2 tons—was about 23 watt-hours for a maximum speed of three miles per hour between locks and an average speed of 1.25 miles per hour between terminals of the canal.

On the electrified portion of the New York, New Haven & Hartford Railroad, during October and November, 1914, the energy consumption per ton-mile of train weight was 27.3 watt-hours in the case of slow freight, averaging 10.85 miles per hour, and 28.5 watt-hours per ton-mile in the case of fast freight, averaging 18.2 miles per hour.* On this part of the New Haven freight runs are comparatively short and power consumption consequently high, and it is safe to say that in the case of a run of 106 miles, under average conditions of stoppage and interference obtaining on double-track railroads in the United States, power required to maintain an average speed of eighteen miles per hour would not exceed that required in the case of The Lehigh Coal & Navigation Company canal in maintaining an average speed of 1.25 miles per hour.

As regards capacity, it will be noted that, even were the locks of the canal between Coalport and Bristol so reconstructed as to permit operation of four-boat tows, the maximum tonnage in one direction during a twelve-hour period is 8150 tons. In this instance the cost of a double-track railroad would not exceed that of the canal, and it is obvious that its capacity would be greatly in excess of the maximum traffic possible through the

*Article by W. S. Murray in *Railway Age Gazette*, April 30, 1915.

canal. For example: a 2500-ton train would carry about 1600 tons of coal, and it would be necessary to pass only five such trains over the road in a given direction during twelve hours to equal the capacity of the canal. On a double-track railroad such trains could be easily operated on thirty minutes headway, which would mean a freight capacity in each direction equal to 4.7 times that of the canal. In the case of the railroad it would be possible, if necessary, to double this capacity by decreasing the headway to fifteen minutes, which, for a speed of eighteen miles an hour, would be entirely practicable.

Without pursuing this subject further, it is evident that, from an economic standpoint, practicable development of our inland waterways is limited to a comparatively small number of rivers, whose channels through a relatively large proportion of their utilizable length are of sufficient depth to permit boats of reasonable draft to navigate them, and which are so located as to permit shipment of heavy tonnage over considerable distances. There are enough of such rivers within the boundaries of the United States to justify the unprejudiced thought of our statesmen and the best efforts of our engineers The amount of money that will be called for in the development of projects of this kind which are economically sound is so great that every expenditure of public or private capital upon power or transportation enterprises which cannot justify themselves when examined in the cold light of economic science, means delay in the development of other enterprises which would constitute valuable additions to our resources in power, transportation and manufacturing industry.

To be presented at the 321st meeting of the American Institute of Electrical Engineers, Washington, D. C., April 26, 1916.

(*Subject to final revision for the Transactions.*)

THE WATER POWER SITUATION, INCLUDING ITS FINANCIAL ASPECT

BY GANO DUNN

ABSTRACT OF PAPER

The endeavor of this paper is to present, from the point of view of the engineer, certain aspects of the attitude of capital towards water powers. Actual and threatened laws, popular prejudices, and some cases of unprofitable developments in the past, have retarded the development of water powers, but there are also physical and natural difficulties which handicap hydroelectric as compared with steam-electric plants, and make it essential that a reasonable profit in promotion be offered, in order to induce investment.

The cost of water power is rising, on account of the increasing cost of labor and materials and increasing taxation, and the efficiency of the utilization of water power has practically reached its maximum. On the other hand, the cost of steam-electric power is falling, in spite of a steady rise in the cost of coal, because continual improvements are being made in the efficiency of conversion of heat energy into mechanical power, and still further progress is to be looked for. To offset this disadvantage there is the possibility of utilizing large amounts of secondary power from hydroelectric plants for industries and process purposes that do not necessarily require continuous power.

The hydroelectric plant usually requires about three times the capital investment needed for a steam-electric plant of equal capacity, and the activity of capital in a hydroelectric plant is very low, much lower than in a steam station and in almost all other branches of industry.

State regulatory bodies have hampered water powers by not recognizing the distinction between bond interest as a compulsory expense paid as the rent for money loaned, and dividends as an earned reward for the risk of the business and skill in management. Another factor that must be more clearly determined in order that the hampering effect of uncertainty may be removed, is the length of time a permit or franchise may run before recapture clauses can take effect, and the question whether these provisions should not cover the power development in its entirety.

Water power should be developed as a matter of conservation, to save our coal supply that is being so steadily depleted. This purpose cannot be served unless the attitude toward water power development is changed and some of the present restrictive factors ameliorated so that investors in water power bonds will be satisfied with five per cent interest instead of requiring seven per cent because of the risks they incur at present.

Manuscript of this paper was received April 24, 1916.

ALTHOUGH the development of water power is almost wholly a matter of civil and mechanical engineering, their interests have been largely in the hands of electrical engineers. Until electrical engineers created the art of transmitting power over long distances the usefulness of water powers was local and the extent of their development did not exceed one million horse power in the United States.

Electric transmission has extended the commercial water power radius during the past two decades from a few miles up to say two hundred. As the art of electrical engineering has progressed and water power has consequently been transformed from a local peculiarity or advantage to an almost universal utility, an intensive development has taken place, energizing for useful purposes thousands of miles of transmission highways and almost innumerable distribution networks with power which formerly wasted itself in the erosion of stream beds and the heating of of their contents.

The profession of electrical engineering has been stimulated by the reaction of this development and has in turn come to depend considerably upon it. Electrical engineers regard the welfare of water powers as identified with the welfare of a large part of their own activities.

The relation of the American Institute of Electrical Engineers to the government of the United States in connection with water powers is an enviable one and is highly valued by the Institute's 8000 members.

In 1911 the National Waterways Commission of the 62d Congress invited the American Institute of Electrical Engineers to send representatives to the hearings of the commission in Washington. In response, the governing body of the Institute created a special Committee on the Development of Water Powers, authorizing it to testify before the commission and put its expert knowledge and experience in every way at the commission's service.

The services of this committee, composed of the country's leading technical experts on water power, were appreciated by the commission and led to the extension of other invitations to the American Institute of Electrical Engineers to send similar representatives to congressional and departmental hearings in Washington in connection with water power legislation. Among these invitations was one from the Secretary of the Interior, one from the House Committee on Arid Lands, one from the

Senate Committee on Public Lands, and more recently one from the Portland Conference of Western Governors, and others.

The governing body of the Institute has continued its special committee in consequence of these successive invitations in view of the apparent appreciation on the part of the government that the services rendered by the American Institute of Electrical Engineers were scientific and professional and not commercial or political, that its committee dealt with fundamental engineering and economic principles of hydroelectric development that were outside the field of controversy, and that the function of the Institute being scientific and professional and not commercial or political, its status was one involving a high degree of disinterestedness in respect to matters on which its technical advice was sought.

The present meeting of the American Institute of Electrical Engineers in Washington is held under the auspices of this committee and is devoted to an engineering and economic discussion of water powers in the hope of turning all the light possible upon the subject.

As indicated by the duties honorably discharged by the Special Committee on the Development of Water Powers, the engineer's function has become considerably broader than one of pure engineering. By a group of promoters seeking capital, the engineer is usually engaged to make preliminary studies and trial designs until he selects the most advantageous site for and determines the most satisfactory miminum cost of a given development. His work, however, does not stop here, for he is called upon next to make studies of the probable market for power and to estimate expected revenue and operating expenses, including taxes and depreciation, and since the relation of engineering and economics is so intimate, the preparation of the economic prospectus falls to his lot.

With such a prospectus the promoters solicit the support of one or more investment bankers, and the name and standing of the engineer is an extremely large factor in securing the confidence of the bankers and in securing their recommendation of the securities of the project to their clients. The criticisms and objections which the bankers constantly raise in reply to the proposals of the promoters have to be answered largely by the engineer, who often reforms his designs many times and has to prove exhaustively his estimates of revenue, capacity, operating expenses and other items before the bankers take up the project,

if they do. Generally speaking and especially in recent years not more than one project in a hundred passes muster.

The engineer therefore usually develops a relation to the financing of water powers, which finds him on behalf of his employers knocking at the doors of capital and using all the abilities he can honorably employ to invite for his employer's project the confidence and support of the experts of capital, and he acquires a knowledge of the conditions capital requires to be met before financing can be accomplished that enables him to take a broader view of the water power situation than one merely from the engineering standpoint.

The other papers presented at this meeting deal with the value of water powers to the electrochemical industries, to the food problem, to increased transportation and to national defense. In this paper I shall endeavor to present very briefly, from the point of view of the engineer as derived from experience, certain aspects of the attitude of capital towards water powers.

It has already been implied that no matter how useful a public service a water power might perform, no matter how great the need of a community for cheap power to invite industrial development, no matter how powerful the river nor high the falls, nor anxious the promoters, a water power plant will not be built unless the investment banker or his equivalent supplies the means.

The investment banker, generally speaking, is not a capitalist, but a captain for the capital of others. They follow his leadership so long as his record warrants it and they gladly yield him a commission in return for sound advice and guidance as to yield and security for the investment of their savings. These others are countless and are in part scattered throughout the earth. The complicated interrelations of capital among the great capital-producing nations are at once intimate and delicate so that capital may truly be likened to an international fluid, quick to flow towards its level of advantage and equally quick to cease flowing when that advantage diminishes. Prior to investment, capital is above the law. It must be consulted and courted or it cannot be won, and it usually requires a good previous character. These are facts, no matter what may be our individual theories of government, of economics, or of social relations.

Part of the acknowledged "water power situation" is due to the scarecrow of financial losses which, contrary to

popular information, have been suffered in water power investments. In cases where losses have not been sustained the actual yield as compared to the expected yield has very generally been disappointing. It seems conservative to assert in respect to a majority of water power investments today, that if the holders were not already in they would not go in if they were free to repeat their investment. Investment bankers of a decade or more ago sometimes piloted their clients with honest confidence into water power projects sound in the prospectus, but so disappointing in the light of later reality as to cost them their financial leadership and render their successors increasingly conservative.

There has been a considerable degree of popular prejudice and misapprehension that conceives water powers to be almost illegitimately profitable. It has had a share in making them the prey of local hold-ups for necessary real estate, flowage rights, relocation of railroads, local taxes and damage suits. But the most serious cause of the above kind that is responsible for the "situation" consists of the inhibition imposed unintentionally, or perhaps it would be better to say unwittingly, upon the investment of capital in water power enterprises, by certain laws, administrative regulations and precedents.

These laws have been both actual and threatened, and in many respects a threatened law is worse than an actual one in the check it gives to investment. Among such actual or threatened laws are those which, limiting the tenure of a grantee, provide for recapture without compensation or with only such compensation as would involve serious loss, or for the recapture of only a part of a system at a fair value for that part, but that part so essential that without it the whole system could no longer thrive.

There is a large group of proposals that look upon water powers as a source of taxation or of government profits through the sharing of earnings. They lay a tax upon energy output, gross receipts, installed capacity or first cost of a development, which tax, although appearing small, amounts to a burdensome and deterrent proportion of the net profits after bond interest.

The grantee is required to construct at his own cost extensive locks and navigation works in cases where he might seem in justice rather to deserve a subsidy for his service to navigation through the erection of a dam that increases the navigability of the stream for many miles and assists in the regulation of its floods. These services, it would seem, at least should relieve him of the burden of additional cost for the locks, which is a drag upon his profits.

Among other menaces to the security and yield of water power capital is the reposing in an administrative officer of the government of a discretion which, while presumably it would never be abused, leaves the possibility of abuse by one of a numerous succession of incumbents, and often causes therefore in effect the title to millions of dollars worth of property to rest upon normal individual discretion instead of upon definitely stated laws that permit the whole of a given future to be securely calculated upon. While clothed with great powers, such officers do not have power to make agreements for the government that may be relied upon as binding the government.

There are also agitated serious objections to the combination of adjacent hydroelectric systems, on the ground that this permits monopoly and may be used to enhance the price of power and light to the consuming public.

With commissions for the regulation of public utility rates in practically all of the states of the Union, the combination of water powers can have no other effect than benefitting the public, for on most fundamental engineering grounds combination either actually reduces operating cost or does the equivalent of it by increasing output for a given capacity. It increases the insurance of continuity of operation and permits reduction of reserve capacity. It reduces the proportion of steam auxiliary power and enables advantage to be taken of excessive rainfall in one area to make up for occasional deficiency in another. The joint cost of distribution lines is diminished, regulation of pressure is improved, and the utilization of powers otherwise too small to be successfully utilized is made possible.

The objection to combination seems to be based upon analogy to combinations in other branches of industry and ignores fundamental engineering principles, especially in the presence of protecting state commissions. Successful opposition to combination could only result in increasing the burdens of both of the public and of the developments.

Many others of the actual or threatened provisions are not only deterrents to investment, but at the expense of the public. In this class fall all forms of taxes on output or development previously referred to. It is sometimes erroneously thought in proposing legislation of this sort that these taxes will be borne by the owners of the enterprises, but they are in fact passed on by them to the ultimate consumers. They are added to operating expenses and rates to the public are increased proportionately. The increased rates check the growth of manu-

factures and growth of the use of light in the community and render it less attractive than other communities where, either through absence of tax or natural advantages, lower rates obtain. With the increasing use of power in manufactures, the attraction of manufacturers to a locality is vitally affected by the rates for power that can be offered. Federal laws proposed for the taxation of water powers have naturally applied only to water powers under jurisdiction of the federal government. They inequitably leave untaxed and free from such discrimination competing private water powers and water powers under state jurisdiction.

It seems difficult on the part of many to accept the conclusion that by the control of rate commissions water powers are forever prevented from becoming bonanzas to their investors. Other kinds of public utility corporations are seen to be duly regulated, but there lurks a suspicion that water powers may form exceptions. While the consequences of this doubt contribute to the complacent retardation of development, the benefits of advancing the development of water powers to communities of large population do not seem to be adequately appreciated.

In some of the governments of Europe so greatly are the benefits of development appreciated that water powers are subsidized and encouraged.

In addition to the laws, prejudices and past financial history that have retarded water powers, there are physical and natural difficulties of a very real sort which render a reasonable profit in promotion requisite to induce investment.

Power developed by a hydroelectric system must be based upon the minimum or nearly the minimum flow of the stream, unless great cost for storage is warranted. The dam, however, must be strong enough to withstand the stream in flood, often 50 to 500 times in this volume. A water power is liable to suffer not only from lack of water in dry season, but it is often partly drowned out at times of flood when high tail water reduces the hydraulic head. For these and other reasons most water powers require auxiliary steam power for reserve.

A large part of a hydroelectric power development consists of transmission lines exposed to lightning, wind and sleet. A water power, unlike a steam power, cannot be commenced in a modest way and allowed to grow as its market gathers. The real estate, dam, rights of way, transmission towers and many other portions of the development must initially be of ultimate capacity and cost, hence during the initial years there is usually a period of waiting for the growth of market when expenses

often exceed income and owners must not only go without their profits but often put up funds to tide the project over.

For taking the construction and operation risks and the risk of delayed development of income, to say nothing of the risks of title, taxes and adverse legislation, it can readily be seen that the profit required to tempt investments into hydroelectric projects must at least be as great, if not greater, than that offer by other utilities or industrials.

So far there have been dealt with only the checks to hydroelectric investment arising from actual or threatened legislation popular prejudice and construction risk, but, especially east of the Mississippi River where three-quarters of the mechanical power in the United States is consumed and where there are still undeveloped large resources of water power, there is an additional check that daily speaks with a louder and louder voice ruling out the water powers—even if financing were obtainable—in favor of steam produced from coal.

Increasingly large numbers of water powers that a few years ago would have been considered worthy of development by conservative financial authorities, assuming all legislative and administrative hindrances removed, are now ranged in the unworthy class because they do not meet the supreme test to which every water power project is put in the engineer's office before it can get even to the preliminary prospectus stage. This test is a comparison of the cost of the power with what it could be produced for in the same market by a steam plant if some competitor should build one there.

The cost of water power in general is rising on account of the increasing cost of labor due to shorter hours in the form of three instead of two shifts and higher wages, the increasing cost of materials, and the generally increasing taxation, employers' liability and similar items of expense that are characteristic of industrial operations generally in the United States. In spite of all these circumstances and in spite of a steady rise in the cost of coal, the coast of steam power is steadily falling.

At equal cost the scales of the consumer's choice turn against a water power and steam power is almost invariably preferred because, among other reasons, it is generated in the market where it is consumed, whereas water power has to be brought from a distance and suffers the risks of a long transmission line. Also steam power is more flexible and is free from the influence of dry seasons or floods. Water power must be considerably the cheaper before it can compete.

The increasing introduction of steam power, devouring our coal fields at a time when millions of horse power of water power are undeveloped, is a crime against the policy of conservation. Each new steam plant is an agency devoted in effect to the perpetual consumption of coal, which is a limited commodity. While absolutely essential for smelting and practically essential for the heating of our houses, it is not essential for the production of power.

Steam power is consumed only when it is used; water power whether it is used or not. If the power of a water fall is not brought to the neighboring city to turn its wheels, do its cooking, or light its lights, the power is developed just the same at the falls and expresses itself in grinding the rocks at the bottom and the heating of the agitated water. Postponement of coal consumption would be real conservation. Postponement of water power development is real waste.

If water power, instead of being at a disadvantage compared to steam power, were fully its equal as to cost of power delivered and certainty of operation, it would still be at a serious disadvantage when construction is under consideration for an added reason which aggravates the whole relation of water power to capital. This is the excessive capital required for a water power as compared to that required for a steam power of the same capacity.

A typical modern steam electric station, including real estate and every other item of cost up to the distribution system, can be built for $45 per switchboard horse power of output. A correspondingly typical hydroelectric development of the same capacity, for moderate head, including transmission lines and substation, would cost in the neighborhood of $135 per switchboard horse power of output, which figures are in the ratio of 1 to 3.

Capital for a steam-electric station is relatively easy to raise. The natural hazards are considerably less. The property is concentrated under one roof, instead of being distributed over many miles of country. There are no actual or threatened adverse laws to introduce doubt as to the security of investment. Popular prejudices are more likely to be favorable to rather than against the economics of a steam station. Large supplies of coal are seen going into it and the public appreciates these must be paid for. The plant, to the popular eye, seems to be hot and busy and entitled to its rewards. For the water power, for reasons that have been mentioned, capital is more

difficult to raise, and besides being more difficult, three times the amount has to be raised. It is not difficult to see why, at equal cost of power delivered if it is a question of building a steam or a water power, the steam power gets the preference, and when, as is increasingly the case east of the Mississippi, the cost of a horse power-hour developed by steam is so much less than by water, the "water power situation" is removed from the court of discussion before a decision is reached, because of the fatal competition of steam.

It may be asked—will the cost of steam power continue to decline, notwithstanding the continued rise in the cost of coal? There seems every reason to expect that it will, for with the best plants of today, improved as they are, the return from a pound of coal is only 17 per cent of the power it contains. Internal combustion engines operated by liquid fuel have not yet cut much figure as large sources of prime mover power, but they are constantly undergoing improvement. In the generation of steam, where boiler pressures of 150 lb. were used a few years ago 275 lb. is now used, and higher pressures up to 400 lb. are under experiment, together with higher degrees of superheat than the past has thought possible, and it is not too much to expect considerable improvement in steam economies from progress already in sight. There is also much latent possibility in the gas turbine. In view of all this, he would be rash who would predict an increase in the cost of steam power, notwithstanding the steady moderate increase in the cost of coal.

While the cost of steam power has fallen and is falling, due largely to an increasing efficiency in the conversion of heat into power, and while this efficiency is still so low as to render further increases not only possible but probable, the efficiency of water powers has practically reached its maximum and further reduction in the cost of water power from improvement in efficiency is barred. Reference will later be made to the only direction in which substantial reduction is possible.

The unfortunate circumstance of excessive capital throws difficulties into the path of water power in more ways than one. Not only is excessive capital required before the development can be created, but after it is created there is a handicap in the magnitude of the bond interest constituting the principal element of cost of operation—using this term in its broadest sense. Both by the large capital required and the large return to capital in its cost of operation, water power development is led conspicuously into the realm of the relations of wealth and capital to

industry and the social system, which are subjects of keen political and economic controversy. The water power problem, being exceptionally dependent upon capital, is the innocent bystander that suffers from the quarrel between two struggling antagonists, both of whom its development would enormously benefit. A unit analysis of the gross operating expenses—using the term as before, in its broader sense—of the typical steam-electric and hydroelectric system I have referred to may be of interest, and is given below for annual load factors in both cases of 50 per cent and coal at $3.25 per ton, delivered.

UNIT ANALYSIS OF GROSS OPERATING EXPENSES IN TYPICAL STEAM-ELECTRIC AND HYDRO-ELECTRIC STATION OF THE SAME CAPACITY, 20,000 H.P., AND ANNUAL LOAD FACTOR 50 PER CENT. COAL $3.25 PER TON DELIVERED.

	Steam station per cent of total gross operating expenses	Hydroelectric station per cent of total gross operating expenses
Administration	4.0	4 0
Ordinary operating expenses (except coal)	10.6	4.8
Coal	48.9	....
Taxes and Insurance	6.7	2.8
Depreciation	10.8	11.0
Bond Interest	19.0	77.4
Total	100.	100.

As will be seen from the table, bond interest is the largest hydroelectric expense. In the typical case considered it constitutes 77.4 per cent of the total operating expenses. In the steam station it is only 19 per cent.

The largest expense in the steam station is coal, amounting to 49 per cent of the total. This everyone can understand and nobody begrudges. There is a small group of opinion that considers all interest usury and to this group the fact that over three-fourths of the cost of producing power in a water power plant represents interest is almost equivalent to saying that the cost of water power ought to be reduced by three-quarters. The whole cost for coal in the steam station is only two-thirds of the cost for interest in the water power.

The classification of bond interest in each case under the head of operating expenses is not customary, but is done for the purpose of giving a clear conception of the radical difference between the compulsory items of expense in the two types of stations.

There is a tendency in many quarters to regard bond interest as profits. This is fundamentally erroneous. It is comparable to regarding the rent a grocer pays for his store as profits. His profits do not begin until after the rent is paid under penalty of

eviction, and similarly the profits of a water power do not begin until after the bond interest, which is rent for the borrowed money, has been paid under similar penalty of eviction by the foreclosure of the mortgage. The holders of the bonds have no interest in the profits of the development. Their return are set by the prevailing rate of interest in the bond market, and not by the prosperity of the enterprise. They get their returns, in theory at least, whether there are profits or not. It is true that bond interest is sometimes in default, but the holders have the right to take possession of the pledged property, foreclosing and recouping themselves for both principal and defaulted interest out of the proceeds of its sale. It is partly by regarding bond interest as profit that the impression that water powers are very profitable has gained acceptance.

It is natural for a spectator surveying a hydroelectric development to gain the impression that the power comes from the water, which, costing nothing, should render the power cheap. It is evident even to a spectator that outside of bond interest the operating expenses of a water power are relatively very low, being in our typical case only 22.5 per cent of the total, which includes ample allowance for depreciation, taxes and insurance. But so much of a dam is in hidden foundations and in parts under water and so much of the long transmission line, rights-of-way and power house and substations is out of view that a spectator, even though liberally inclined towards the deserts of capital, constantly underestimates the amount of capital invested and neglects to include in his conception of the cost of the power, adequate charges for the service of the capital.

Business men know that profits depend not only upon excess of price over cost of product, but on " turn-over— ", which is the ratio of aggregate sales to capital.

If we compare a steam-electric with a hydroelectric power of the same capacity in both of which the selling price of a horse power-hour is the same, we must permit out of this selling price a greater proportion of gross profit in the hydroelectric or we cannot yield the same return to capital, since there is three times the capital to be served. In other words, there is only one-third of the " turn-over ". The activity of capital in a hydroelectric plant is very low, much lower than in a steam station, and much lower than in almost all other branches of industry such as manufacturing.

Certain public service commissions have hampered water powers by not recognizing the distinction between bond interest

as a compulsory expense paid as the rent for money loaned, and dividends as an earned reward for the risk of the business and skill in management. They have in effect ruled that the total return for bond interest and dividends together must be limited to a certain amount—eight per cent in the recent decisions in California. The result of this in attempting to secure new capital at a time when bond interest rates are tending to rise is going to be the same as if the grocer, when his rent was raised due to improvement in the opportunities of the neighborhood, should be ordered to accept smaller, instead of larger profits to keep the total of his rent and profits the same. If he were free, he would decline to do business under such conditions, and if not free his plight would warn others.

There has been considerable discussion surrounding the length of term for a permit or franchise after which recapture clauses can take effect, and those interested in water power are not agreed seemingly because of difference in approach to the problem rather than difference in conviction as to the effect of certain provisions.

For a simple water power unrelated to others and not expected to grow, a fifty-year term might seem long enough to remove from influencing the raising of capital discussions concerning the favorable or unfavorable developments final to the term. Those who are less concerned over final conditions are often, although sometimes unconsciously, relying upon the extreme improbability of the exercise of the right of recapture, with such loss as it might involve.

Ten years of the fifty would often run between the granting of a permit and the time a bond issue was put out and construction commenced, and three years more would often run before operation began, so the recapture conditions might indeed come within the life of a forty-year bond and have a sentimental, if no other, effect upon its acceptability and price.

But growth is a characteristic of successfully located and successfully managed water powers, and ten years after the completion of construction perhaps the development a second location further up stream by the same company becomes desirable. While a fifty-year permit for the new development may have no disadvantages, the new bonds of the company must take into view the approaching expiration of the permit on the first development, which now is only 27 years off, and by the time a three-year period of construction of the second development is completed, will be only 24 years off.

We now reach a time when it becomes of the highest importance to know just what the conditions and effect of recapture will be. If we are successfully to solicit capital for our new venture and if we are to continue to be able to invite industries to locate and develop in our territory, building extensive factories and communities in the security of long-term power contracts, the possible recapture of the original development must contemplate taking over not only the dam site, which is all certain proposed laws have included, but the transmission lines, substations, steam auxiliaries and all appurtenances and adjuncts that make the development an operating whole. The existing power contracts and all other contractual obligations of the development should also be part of the obligation of recapture.

In default of this the application for new capital will be unsuccessful, fearing a limitation of opportunity and a disorganization of the management and possible liability for unfulfilled contracts and possible loss from recapture at depreciated physical, instead of fair, value.

If recapture is to be on terms involving a known definite loss—in several bills reversion of dam and power house without compensation has been proposed—an appropriate sinking fund must be set up to offset this. Suppose such a sinking fund to be one per cent of the cost of the original development and to be set up thirty years in advance of the expiration of the permit. This 1 per cent expense seems small; but if we consider that the total return on the cash cost is not likely to average over 10 per cent, of which, for purpose of illustration, 7 per cent may be regarded as bond interest and 3 per cent as profits, the 1 per cent sinking fund for the amortization of the loss of recapture would absorb one-third of the profits of those owning the equity in the venture and bearing the risks and earning the rewards of management.

Reference has been made in only a general way to term of permit and conditions of recapture in illustration of the kind of problems these questions throw into the path of promoters and engineers seeking to make water powers attractive to capital.

A number of their chief impediments are removed and water powers take on a new aspect when viewed as a source of secondary power in addition to their primary power. Capital for a given output greatly diminishes, market is rendered more stable, transmission lines are cheapened, since industries that use secondary power can locate near the development, and the cost of such secondary power manifests itself so low as to help to restore the effective competition of water with steam. In many cases secondary water power would be so much cheaper than

steam that impetus would be given to the creation of industries and industrial processes now dormant because the cheapest steam power is too expensive. For process purposes, continuous or primary power is not necessarily required, and advantage can be taken in large numbers of cases of the enormous amounts of water power in excess of minimum flow or of partly equalized flow now wasted in other than the dry seasons. If by wise provision we can nourish our struggling water powers with the increased revenue which, generally speaking, without interfering with primary power, secondary power could yield, the total cost of both services would be so greatly reduced that water powers would again in a large number of cases assume the place they held before steam power became so cheap, and, east of the Mississippi, began to rob them of their birth-right. The water powers would then be able to conserve coal, up-build communities by cheap power, and encourage to locate in this country industries that now go elsewhere.

If, in addition, the attitude of the public, and in harmony with it the attitude of the public service commissions and of the government should change toward water powers so as to regard them as friends, capital would flow liberally again and the public, the government, the capitalists, the promoters and the engineers would all be highly benefited and rewarded.

But even independently of the cultivation of secondary power a great deal can be done to develop our water powers as they are, especially west of the Mississippi where three-quarters of the water power resources lie, and where, generally speaking, on account of the high cost of coal, water power is normally cheaper than steam power. While for the time being the Pacific and some of the mountain states seem to be over-developed in respect to water powers, lacking market, rather than development there are numerous specific cases where development is urgently needed but deterred by the considerations that have been mentioned. Power consumption per capita in the United States is increasing so rapidly that unless we wish to shut our eyes to the staggering rate at which we are making inroads upon our exhaustible coal supplies, the development of our water powers is imperative.

The West needs them to get a cheaper power than the relatively high-priced coal and oil afford, and with this cheaper power can in time work wonders in industrial and agricultural development. The East needs them as a source of power cheaper still than the already cheap steam power and as a substitute for the fuel-produced power that is eating out the vitals of our fuel

resources, which should be conserved for purposes that only fuel can serve.

The water power situation is costing the country many millions annually in actual loss and in retardation of industrial development.

It has been shown that reduction in the cost of water power cannot be expected from further inventions or improvements in the art of engineering, but the cost of water power is susceptible of considerable reduction nevertheless from improvements in another direction.

In our typical case 77.4 per cent of the cost of production of a horse power-hour was composed of bond interest. The table was compiled on the assumption that money was worth seven per cent for water power purposes. If its owners could be induced to lend it for five per cent the bond interest would be reduced to 28 per cent and the cost of production of a horse power-hour 22 per cent—a reduction important enough in many cases to turn the scales against steam power and result in the bringing of a new water power into existence.

Or if the case occured in the West, a 22 per cent reduction in power cost would go a long way to enable the use of power for purposes previously out of its range.

A five per cent bond interest for the typical case is not visionary. Railroads enjoy it and many industrials.

Water powers could enjoy it if there were a change of policy on the part of the public, the commissions and the government toward them that made investments in them secure, removed all but the property taxes they now bear, eliminated the many extra construction costs, expenses, delays, technicalities and injurious limitations they suffer, and brought them to a position of being under the fostering care of the government as a boon to the public.

The writer, for one, thinks this change will slowly come. It has already started. Little by little the interests of the parties to the controversies are being discovered to be identical. Little by little publicity and the pure light of intelligence will permit economic laws to have their free play and the "water power situation" will disappear, giving place to a rapid development that will benefit our citizens as consumers, strengthen old and develop new industries and save our coal, putting us in a superior position not only with respect to power but in respect to the influence power is having upon the development of all the resources of the country.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

SUGGESTIONS FOR ELECTRICAL RESEARCH IN ENGINEERING COLLEGES

BY V. KARAPETOFF

ABSTRACT OF PAPER

The primary object of the paper is to present a list of topics in electrical engineering suitable for thesis, research, and advanced study. A plea is made for systematic research, each college specializing year after year in only a few topics for advanced investigation. The author suggests that the Educational Committee of the Institute become a central place for information and a stimulus in applied electrical research, cooperating with engineering colleges and with individual inventors and investigators.

Various types of investigations are enumerated, such as invention, experimental study, theoretical study, library search, and compilation of data. Some advice is given the young investigator as to how to proceed in the most efficient way and to avoid a disappointment.

"WHAT topic shall I choose for my required thesis?" This is a question that will sound familiar to a teacher in electrical engineering. Sometimes the students puts the question in this way: "I have some spare time and should like to do research work; what would you suggest for a subject?" Again, once in a while a young practising engineer writes that he does not wish to become " rusty " and asks that a subject be suggested for systematic study in the evenings. Truth forbids the statement that such inquiries come often enough to be burdensome; nevertheless the writer found it convenient some years ago to compile " A List of Electrical Subjects for Thesis, Research and Advanced Study," as a ready reference in answering such inquiries. This list was privately printed in 1909 and has been used since by a number of the author's colleagues in various engineering colleges.*

A revised and augmented list is now offered to the profession in the hope that it may prove useful and stimulating to students,

*For a similar list of topics in mechanical engineering see H. Wade Hibbard, "Thesis Directions for Students," Proceedings of the Society for the Promotion of Engineering Education, Vol. 21 (1913) p. 129.

to teachers, and to engineers who are interested in research, invention, and advanced study in electrical engineering.

The author also recommends that the Educational Committee of the Institute revise this list from time to time and keep it up to date, soliciting additional suggestions from various technical committees, from prominent practising engineers and from teachers. In this manner the Educational Committee would in time become a source of information and stimulus for organized electrical research.

Anyone who follows European electrical periodicals will agree that this country is behind Germany and England in the invention of new types of electrical machinery and apparatus, in the discovery of new electrical phenomena, and in the development of working theories and numerical relations needed in our profession. Whatever the causes of our backwardness, we must find a remedy for it, and the most important first step is to systematize and organize research.

The American Institute of Electrical Engineers has not limited itself in the past merely to recording the progress of the art and the opinions of its members. Through its committees and representatives the Institute has participated in the solution of a number of important national and international problems, and it has never failed to take an active interest in activities by which it was able to render important service to the profession and to the nation.

The promotion of organized research in engineering and the encouragement of young men to train themselves in the art of invention is at present an important national problem, if we are to rank with the leading European nations and to be independent of them in times of need. The author has emphasized elsewhere more in detail the importance of *systematic* research and of encouraging the art of invention among young engineers.* The national engineering societies are naturally called upon to lead in this movement, and the American Institute of Electrical Engineers ought to do its share. In fact, one of the principal objects of the Institute, according to its

*See his paper entitled "What has Engineering Education contributed to Scientific Progress and Invention," presented at the second Pan-American Scientific Congress in Washington, D. C., on Dec. 31, 1915, and published in the Bulletin of the Society for the Promotion of Engineering Education, April 1916, p. 597. See also J. A. Fleming, "Organization of Scientific Research," *The Electrician*, (London), Feb. 18, 1916.

constitution, is "the advancement of the theory and practise of electrical engineering and of the allied arts and sciences."

The Educational Committee of the Institute could well carry on this work if some of its members were selected with this purpose in view, and if it could arrange for cooperation with the other technical committees. This would be a distinct field of activity closely connected with the rest of the work of the Institute, and at a safe distance from the work of special educational societies, especially the Society for the Promotion of Engineering Education. This new activity of the Educational Committee of the Institute might be carried on as follows:

1. The Educational Committee could announce in the PROCEEDINGS and by letter to the electrical departments of the technical schools in North, Central, and South America that it is prepared to assist the students and young engineers by suggesting topics for research, invention, and advanced or special study.

2. The Educational Committee could regularly collect and publish suggestions as to timely topics for research from the technical committees of the Institute, from manufacturing and operating concerns, testing laboratories, consulting engineers, prominent scholars, etc.

3. The Educational Committee could collect information as to the facilities for research available in different schools, and the problems already solved or under investigation. The principal schools might be induced to conduct certain researches in cooperation, rather than to duplicate work. Each school ought to specialize in research along a few definite lines year after year, in accordance with the facilities available and the relation to the local industries. In this manner valuable results could be achieved, whereas now the attempts are mostly sporadic, leading nowhere.*

4. The principal results of research might be published regularly in abstract in the PROCEEDINGS, and thus made of general use, where now they are simply filed in college libraries.

*Perhaps the most instructive case of systematic research carried on through many years was that at the Elektrotechnisches Institut in Karlsruhe, under the inspired guidance of the late Engelbert Arnold (1856-1911). As a result of this work we have several volumes of the most accurate and useful information on dynamo-electric machinery and numerous valuable inventions; while scores of Arnold's former students all over the world, are prominent as inventors, investigators, designers, and scholars. In this country Professor Harris J. Ryan with his students has carried on investigations on dielectric stresses for years with splendid results.

5. The Educational Committee from time to time should publish in the PROCEEDINGS a brief account of the most important progress in apparatus, methods of measurement, mathematical relations, etc. In these accounts emphasis should be placed upon the method of attack, logical reasoning, patience of the inventor or the investigator, the importance of a clear knowledge of physics, mathematics, mechanics, and chemistry, and in general all such facts as may encourage young investigators and help them in their own research.

6. The Institute might announce each year one or more prizes and medals for the best improvement in apparatus, measurement of some difficult quantity, the best theoretical investigation, etc. These prizes need not be over $50 to $100 each, and the money can be easily appropriated out of the general expense fund of the Institute. Prizes might also be announced for the solution of definite problems of special importance in manufacturing and manufacturers might be induced to furnish money for them.

7. The Institute could help both the electrical industry and the colleges by inducing larger electrical concerns to maintain industrial scholarships in engineering colleges that are prepared for the work. Such scholarships have proved very useful in chemical industry, and in the manufacture of cement, steel, etc.

8. The Institute might pave the way and lend its influence towards the foundation of a National Institute for Electrical Research, or even a National Institute for Engineering Research, similar to some existing institutes for medical research.

GENERAL REMARKS

1. The list printed below is by no means complete or exhaustive and is primarily intended to be suggestive. It would of course be out of the question to write out in detail the purpose and the program of every possible investigation in electrical engineering. The important preliminaries to almost any bit of research are to find out the present status of the problem, to formulate what is needed, and to devise the means for carrying on the investigation. Having selected a general topic the student should make a search in the literature of the subject, consult his instructors, and if necessary take the matter up with outside specialists.

2. The topics are suggested in general terms only, because it is not supposed that a beginner would use the list. If neither the student nor his teachers know anything about the present

status of a certain topic, it is hardly likely or even advisable that the student should take it for his thesis. He needs an elementary text-book on the subject. If, however, at least one of them knows something about the particular topic, its mention in the list will be sufficiently suggestive, and will recall to his mind certain definite problems to be investigated, and he will know where to go for some first-hand information on the subject.

3. Each technical college will find it more effective and more useful from an educational point of view to induce successive students to continue each other's investigations for a term of years until definite results have been achieved. The college can then afford to invest a considerable sum of money in apparatus and will develop real experts among its faculty who supervise this research. With a proper selection of a few topics this policy would in a few years lead to the formation of a valuable specialized experiment station.

4. As far as possible, only subjects of vital interest have been selected for the list, although the author does not believe that the immediate applicability of the results is of prime importance. What counts is the ability to size up a situation; to obtain the necessary information; to concentrate one's whole attention and interest on a problem, and to get definite results. Facts and relations that are of no practical use today, may become very important presently.

5. Much valuable work can be accomplished by colleges and their advanced students through exercising a wise foresight as to future developments in the electrical industry. Often manufacturers feel disinclined to experiment on subjects whose commercial usefulness seems remote, and here is where a college can blaze the way, clear the situation, perform the first preliminary experiments and bring the results to the attention of those who may continue the work on a larger scale and with more accurate means.

6. A résumé of the present situation is needed in most of the important topics for research. Sometimes a student without much imagination but with plenty of patience may be utilized for this preliminary work; he may thus become a useful contributor to the solution of a problem where he would have failed if allowed to undertake an original investigation. It is earnestly urged that students and others interested in the progress of our profession do more of this kind of work, describing in a connected and critical manner what has been done, how it was done, where the information is to be found, and what remains to be done.

Such information freely published in magazines and transactions would not only serve as a powerful stimulus for research, but would relieve able investigators and inventors of a great burden.

Principal Types of Investigations

(a) *Invention or improvement* in apparatus, in connections, in materials, in methods of manufacture, etc. If possible, always take an investigation of this kind, because the progress of engineering art depends essentially upon invention.

(b) *Search in the patent records of the United States and foreign countries* with the view of determining the state of the art in a particular subject or branch of industry. Such a search often saves a great amount of labor, expense, and bitter disappointment later on. Moreover, a thorough knowledge of the combinations and means used by other inventors sometimes suggests one of the remaining combinations not covered by patents, or an improvement in the preceding inventions. If students and young engineers would do more of this class of work and less promiscuous inventing, we would have fewer annoying and disappointed inventors, and more inventions of real value.

(c) *An experimental investigation* of some device or group of devices, a material, a process, etc., to determine the effect of certain factors, for future guidance.

(d) *A theoretical investigation* of some relationship or phenomenon, with the view to explaining or generalizing certain observed facts; also to predict performance, to enable the designer to proportion a piece of apparatus, to avoid some harmful effect in operation, or to take fuller advantage of some beneficial effect.

(e) *Compilative* or semi-compilative work, such as systematization of notation or nomenclature; comparison of theories, experiments or data of various investigators: unification and simplification of procedure in design or in other computations; preparation of tables, curves, formulas, etc., for a particular purpose; bilbiography of a given topic, etc.

Advice to the Young Investigator

1. One who hopes to succeed in invention or research must possess persistence, accuracy, imagination, resourcefulness, good general education (so as to borrow methods from other branches of science) and in addition some special knowledge or skill directly pertaining to his problem. It may be experimental skill, dexterity with tools, mathematical ability, knowledge of foreign languages,

etc. Often an attempted research ends in failure not because of alleged external difficulties but because the student selected the wrong kind of problem; for instance, one requiring experimental ability, when his strong point is library research. An insufficient knowledge of the fundamentals of one's profession often results in a failure in research, though it is sometimes difficult to convince the student of the connection between the two.

2. Before taking up a piece of special research ask yourself if the same time could not be more profitably spent in a study of some more general topic in electrical engineering. For example, would you spend, say, half a year in experimental research of the effect of wave-form of the applied voltage upon the core loss in a transformer, or would it be more useful for yourself to put the same time in a study of books and articles on transformers in general, their theory, construction, design, connections, etc.? This question no one but yourself can answer.

3. Remember that in practically every case you expect to continue the work of others; therefore be particularly careful to find out what has been done, avoid duplication, and give due credit to the preceding investigators. The literature search may be properly begun with the "Science Abstracts," Part B, Electrical Engineering. In some cases Part A, Physics, must also be consulted. The corresponding German publication "*Fortschritte der Elektrotechnik*" is also excellent and perhaps more systematic; in addition to abstracts and periodicals it contains new books and patent specifications. The well known "Engineering Index," and the card catalogues arranged by topics and found in the Engineering Societies Library in New York, in Carnegie Library in Pittsburgh and in large college libraries are also great helps. The indexes to the leading electrical magazines and transactions should also be consulted.

4. When planning some research or invention try to think of it in the light of the past and future development of the subject, and not as a detached little investigation of your own. This means that you must connect your work with that of former investigators, and present your results in definite form so that the following investigators can connect them with their work and profit by your labors.

5. There are problems on which no one is working, either because the situation is premature, or because others became discouraged through lack of results. There is an advantage in working on such a problem. Should you succeed, your credit

and recognition will be so much greater. On the other hand, you are much safer working on a problem already staked out by others, where you are merely developing a detail. Some prefer exploring the wilderness, others keep near to beaten paths.

6. Almost any problem mentioned in the following list may be made as short and elementary or as long and thorough as is desired, from a superficial undergraduate thesis finished in a few weeks, to an expert's deep research carried on devotedly through a long series of years. Do not "bite off more than you can chew," but whatever you decide to do, do it well.

7. Do not try to maintain secrecy regarding your work, but try to draw into it and to interest in your problem as many other able persons as you can. Both you and they will be benefited thereby. Consider yourself to be but a thief's apprentice who is learning how to steal nature's secrets, but is not actually doing it yet.

8. Having made a patentable invention or obtained a patent do not try to hold it for an exorbitant price. Dispose of it on the basis of a reasonable sum down and a moderate royalty per year or per piece sold. If you have a real inventor's stuff in you, you will make many more important and lucrative inventions. Dispose of your first effort as soon as possible; it will be an encouragement for your further work.

Electric Generators and Motors

Output Coefficients. Theoretical justification and limitations of the D^2L formula.

Values of flux density, ampere-conductors per centimeter of periphery, and current density in actual machines.

General study of the best utilization of active iron and copper.

Elements of cost of machinery.

Heating and Ventilation of Machinery. Flow of heat along and across laminations, along copper conductors, across slot insulation, through thick field coils, etc.

Heat transfer between various surfaces and the air, stationary and in motion.

Temperature distribution in a given machine, and bettering its performance by more effective cooling.

Forced ventilation.

Cleaning and cooling of the air.

Rating for intermittent service.

Commutation in Direct-Current Machines. Actual phenomena of commutation with and without interpoles, by means of oscillograph.

Commutation on a device imitating an actual armature coil.

Interpoles, effect of their width and saturation; inductive shunts.

Effect of compensating windings on performance.
Study of brushes.
Proposed formulas and theories of commutation, a critical review of.
Approximate methods of integration of the differential equations of commutation.

Mechanical Construction and Stresses in High-Speed Machinery. Support of armature coils; dovetail stresses; vibration of shaft; stray currents in shafts; fastening of field coils; high-speed commutator; stresses in stationary frame; eccentric rotor.

Armature Reaction and Inductance. Armature reaction in d-c. machines.
Armature reaction in polyphase and in single-phase alternators.
Proposed methods for compounding alternators.
Exact theory of armature reaction and practical approximations.
Leakage inductance of windings, and the separation of slot leakage, end-connection leakage, etc.
Theoretical predetermination of leakage inductance.
Transient condition during short-circuit.
Hunting.

Polyphase Induction Motor. Proposed methods for speed regulation.
Performance characteristics and circle diagram above synchronism.
Predetermination of power factor from design data.
Magnetic leakage and its components.
Exact circle diagrams of performance.
Magnetizing effect of distributed windings.
Experimental separation of losses.
Methods for accurate determination of slip.

Single-Phase Induction Motor. Proposed methods of starting.
Rating of the same frame for one, two, and three phase windings.
Design of a single-phase induction motor.
Experimental and theoretical investigation of the elliptical revolving field.
Circle diagram of a single-phase induction motor.

Single-Phase and Polyphase Commutator Motors. History of development.
Classification of types.
Means employed for improvement of commutation.
Performance diagrams of the principal types of commutator motors.
Comparison from the point of view of speed-torque characteristics.
Comparison from the point of view of commutation.
Experimental study of a commutator motor.
General principles of design.
Complete design of a single-phase railway motor.
Design and construction of a working model, imitating the electrical relations in a commutator motor.
Phase adjusters for improving power factor.

General Design. Factors to be considered in the design of a new line of machines.
Critical comparison of procedure used by various authors.
M. m. f. required for the active layer.
Design of a line of small machines for manufacture in large quantities.

Layout of a factory for production of a given line of electrical machinery.

Improvements in Methods of Testing. Critical study of methods for measuring temperature, core loss and the separation of hysteresis from eddy current.

Measurement of friction and windage.

Resistance measurements.

Methods of loading a machine by means of circulating power (pumping back methods).

Measurement of speed, slip and acceleration.

Load losses in single-phase alternators.

Special Types of Electrical Machinery. Homopolar generator, reduction of brush friction, increase in speed.

Constant-current machine for operating large arc projectors.

Train-lighting generator driven from car-axle.

Automobile starting motor and lighting generator.

Magnetos for ignition.

Synchronous motor with high starting torque.

Electric variable-speed drive for automobiles.

High frequency alternator for radio work.

Motor-generator set for intermittent load with energy stored in a flywheel, such as are used in steel mill and mine-hoist work.

Combination of an induction motor and a polyphase commutator motor.

Motor-converter consisting of an induction motor and a d-c. generator with inter-connected windings. Permutator or a converter with stationary field and armature and revolving brushes. Thury high-tension d-c. constant-current machine.

Battery boosters and counter e. m. f. sets.

TRANSFORMERS

Leakage Reactance. Experimental investigation of the influence of arrangement and shape of coils.

Theoretical formulas derived from the equations of electromagnetic field.

Influence of unequal distribution of current in large conductors.

Internal vs. external reactance for safety of large systems during short-circuits.

Economic Relations. The best distribution of losses for a given service.

Amount of copper and iron as a function of relative prices of these materials.

Best values of flux and current density.

Influence of Wave-form. Effect upon the voltage drop, upon the iron loss, and upon the stresses in dielectrics.

Temperature Rise. Theory of conduction of heat; experimental data; influence of various factors; safe temperature rise with various materials; devices for forced cooling.

Artificial load for heat run.

Extrapolation of heating and cooling curves.

Connections. Comparison of delta and Y-connections under normal and abnormal conditions.

Analysis of currents and voltages in *T* and in *V* connections.
Doubling the frequency by means of two transformers.
Electrostatic Stresses and potential gradient in and around bushings, terminals, between coils, etc.
Extra stresses due to transient conditions.
See also the section on Dielectrics.

Power Plant Design and Economics

Standardization of electrical equipment for smaller plants.
Elements of first cost and of operating expenses.
Rational methods of charging for energy.
Forms and blanks for accounting.
Safety appliances, emergency devices, labor-saving apparatus.
Parallel operation of power plants.
Division of load between a steam and a water-power plant.
Uses of storage battery.
Automatic substations.

Transmission Lines and Cables

Mechanical stresses in towers and in conductors; influence of temperature.
Skin effect in copper covered and steel wire and in stranded cable.
Interference between power and telephone lines; theory, calculation of induced currents, experimental investigation, methods for reducing interference; the general problem of transposition.
Locating faults with the line energized or dead.
Protection against grounds and short-circuits, sectionalization, relays.
Actual experience with lightning and possible conclusions.
Various types of protection against lightning.
Theory of the ground wire.
Current and voltage relations in lines with distributed properties.
Standing and traveling waves; surges and protection against them.
Experimental mechanical apparatus imitating electric waves.
Transient electric phenomena studied experimentally and theoretically.
Kelvin's law of economy and its various practical applications.
Computation of electrostatic capacity and stresses of cables.
Reduction of capacity in telephone cables.
Propagation of signals in submarine cables.

Electric Traction

General Projects. Design of a high-speed underground road for a large American city.
Design of an elevated road for local and express trains.
Electrification of a large steam railroad center.
Electrification of a mountain division of a steam railroad.
Gasoline-electric and straight gasoline cars for light traffic.
Storage-battery car.
Trackless trolley car.
Competition of the motor bus and of the "jitney" with city, suburban, and interurban railways.

The electric truck.
The electric passenger vehicle.
The dual power car.
Electric traction of boats on a ship canal.
Design and organization of repair shops for a large electric-railway system.

Track, Trolley, Signals. Standardization of the materials, and of the methods of operation and maintenance.
Rail corrugation.
Continuous rail, electric welding, thermit welding.
Bond testers.
Stray currents and prevention of electrolysis.
Overhead construction in various classes of service.
Mechanical stresses in trolley wire, in messenger cables, and in the supporting structures; the problem of support on curves.
The surface-contact system.
Sectionalization of trolley circuits in freight yards, in large passenger terminals, etc.
Automatic switching.
Automatic signals.
The problem of safe and quick dispatching of high-speed roads.

Rolling Stock. Quick and accurate predetermination of time-speed curves.
Design of an apparatus for automatic tracing of time-speed curves.
Resistance to motion of single cars and trains.
Special equipment of an electric car or locomotive for various tests and experiments.
Single-phase locomotive with an electro-dynamic converter or with a mercury-vapor rectifier.
The possibilities and limitations of high-tension direct-current traction.
Recuperation of power on electric roads.
Control of high voltages or of heavy currents in an electric locomotive.
Various types of drive; gears, side-rods, direct drive.
Electrically controlled air-brakes for high-speed roads.

Electric Lighting*

Light sources: proposed standards; new types of electric lamps; position and shape of filaments, temperature of operation; color characteristics, and effects; design for special purposes; operating mechanisms.

Lighting accessories; optical properties of diffusing and reflecting media; globes, shades, and reflectors for special purposes; "daylight" glass; means for eliminating glare.

Visual photometry; sensibility of photometers; size of photometric field; errors due to instruments; errors due to operator; effect of color sensibility of observer; recording devices; calibrating devices; integrating photometers; flicker photometers; standardization of absorbing solutions; means for eliminating color differences; standardization of conditions of measurement.

*Contributed by Professor F. K. Richtmyer.

Physical photometry: the selenium cell; the photoelectric cell; the bolometer; the thermopile; absorbing solutions; photographic methods; other chemical methods; new methods.

Studies in illumination: Survey and criticism of present conditions in various types interiors, in streets, etc.; intensity and type of illumination necessary for various purposes; eye fatigue and visual acuity as dependent on intensity of illumination, color, and system used; design of systems of illumination; illumination calculations.

Terminology of illuminating engineering.

Relation of art, architecture, physiology, and psychology to illuminating engineering.

Application of Electric Motors*

Industries. Agriculture, automobile, bakeries, boiler works, bottling works, box factories, breweries, brick factories, broom factories, building construction, candy factories, carpet and rug factories, cement, clothing, corn mills, cotton mills, cotton oil seed mills, creameries, dairies, dye works, flour mills, foundries, freight handling, glass factories, glove factories, hardware manufacture, harness factories, ice machines, irrigation, knitting factories, laundries, lumber mills, machine shops, paper box factories, paper and pulp mills, piano factories, pipe mills, planing mills, porcelain factories, railways, refrigeration, rubber industry, shoe factories, shoe repairing, soap factories, spice factories, steel mills, stone quarries, stove factories, sugar industry, tanneries, textile mills, tile factories, tobacco factories, trunk factories, wagon factories, wall paper factories, woodworking factories, woolen and worsted mills.

Classes of Service. Air compressors, blowers, coal cutters, concrete mixers, conveyors, cranes, crushers, dental appliances, dredges, elevators, exhausters, fan, hoists, ice cream freezers, lime kilns, locks, pumps, printing presses, rock drills, sewing machines, ship propulsion, towing machinery, turn-tables, vacuum cleaners, vehicles, washing machines.

Measuring Instruments and Methods

General. Study of characteristics, errors, cost of manufacture, etc. of a given type of meters.

Development of a new type to meet competition in price or to avoid infringing certain patented features.

Design of a complete calibrating equipment for a manufacturing concern, an operating company, a testing laboratory, a college, etc.

Special instruments, such as a double tariff meter, a maximum-demand indicator, a volt-ampere meter, an automatic synchronizer, a phase displacement meter, instruments, for recording rapidly-fluctuating currents and voltages, etc.

Instrument transformers. Design, methods of calibration, errors, exact theory, vector diagrams, etc.

Extra-Accurate measurement of various quantities used in electrical engineering, viz., current, voltage, power, resistance, inductance,

*Contributed by Mr. D. B. Rushmore.

capacity, speed, acceleration, slip torque, magnetic properties, dielectric properties.

Analysis of methods, errors, applicability in various cases, new devices and new diagrams of connections.

Magnetic Measurements. Measurement of permeability, core loss and retentivity.

Effect of composition and treatment of steel upon its magnetic properties.

Heusler alloys.

Experimental investigation of distribution of a magnetic field, using an analogous condition of flow of heat or electricity through metal, or flow of water.

Detection of flaws in rails by a magnetic method.

Relays. Overload, underload, and reverse load; over or under-voltage, high and low frequency, low power factor.

Merz-Price and similar selective arrangements.

Time characteristics, instantaneous, definite time, inverse time, etc.

Relays for regulating voltage of generators, batteries, feeders, etc.

Regulation of power-power factor, frequency, speed, etc. by means of relays.

Relays for submarine telegraphy.

Radio Transmission*

Methods for producing damped oscillations for transmission purposes.

Methods for producing damped oscillations of particularly constant amplitude for laboratory measurement purposes.

Methods for producing undamped or continuous oscillations for transmission purposes.

Study of radio detectors.

Study of radio amplifiers.

Study of the "beats" receiver and methods for producing oscillations for the same.

Comparison of "tikker" and "beats" receiver for the reception of undamped waves.

Advantages and disadvantages of using the "beats" receiver for damped waves.

Directive radio communication. Study of the variation of signal intensity with varying wave lengths. Methods of modulating the antenna current for radio-telephony.

Design of a compact portable decremeter.

Study of radio measuring instruments.

Design and construction of portable radio sets.

Design and construction of radio apparatus suitable for instruction and demonstration.

Modern theories of propagation of electromagnetic waves (without mathematics).

Experimental determination of "radiation resistance."

Mathematical theory of radio transmission.

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*Contributed by Mr. C. W. Ballard.

Dielectrics

Experimental study of various insulating materials under various conditions of service.
Theory of dielectric stresses in two dimensions by means of conjugate functions.
Experimental investigation of distribution of an electrostatic field using an analogous condition of flow of heat or electricity through metal, or flow of water.
Surface resistivity.
Design of high-tension insulators, bushings, transformer insulation, etc.
Reliability of spark gaps of various shapes.
Measurement of extra-high voltages.
Design and construction of a transformer for testing purposes.
Study of insulating oils; development of a practical and reliable test.
Compressed gas as electric insulation.

Miscellaneous Problems

Agriculture, electricity in.
Amplifiers for weak currents and voltages.
Arc phenomena.
Automobile starting, lighting, ignition.
Atmospheric electricity, oscillograph study by means of an antenna.
Circuit breakers.
Electromagnets.
Farm lighting and power.
Fixation of atmospheric nitrogen.
Fuses.
Heating and cooking; heat accumulators; high-resistivity alloys; temperature control· insulation.
Magnetic separation of iron ores.
Marine applications of electricity; electric drive of an ocean steamer.
Pictures, transmission of, by electricity.
Precipitation of suspended matter; smoke abatement.
Rectifiers, aluminum, cathode ray, mercury, revolving, vibrating contact.
Safety rules, standardization rules, and standard specifications of various associations in this country and abroad; a critical comparison.
Submarine signaling.
Thermo-electricity, generation directly from fuel.
Telegraphy, rapid, multiplex, submarine with alternating currents.
Telephone apparatus for the deaf.
Telephone transmitters of great power; sensitive telephone receivers and relays, phantom circuits.
Water purification by electricity.
Welding, electric.

APPENDIX

In connection with the suggestion that the A. I. E. E. should encourage systematic research under the auspices of its Educa-

tional Committee, the following description of the organization and work of the Research Committee of the A. S. M. E. is given by Mr. R. J. S. Pigott, a member of the committee.

The object of the Research Committee is to promote the investigation of phenomena, operations, or results of experiments concerning fundamental laws on which engineering practise is based, and to place such data in permanent and basic form. The general committee meets at stated intervals to consider suggested research subjects and to appoint sub-committees to do the actual work of research. Generally, the chairman of the sub-committee is a member of the general committee, but not necessarily so. The present sub-committees are those on fuel oil, materials of electrical engineering, safety valves, worm gears, lubrication, clinkering of coal, steam flow meters, laboratory systems and methods; and a committee on investigation of machine tools is under consideration.

The chairman and members of the sub-committee either carry on research in their particular field, themselves, by cooperation with manufacturers, or else have the work done by an interested manufacturer. In general, the expense of the research is borne, therefore, by the interested parties and not by the society.

Up to the present time the committee has not presented any final reports, but the work on worm gearing is well under way, and also that on steam flow meters. As research work is usually lengthy, final reports in less than two or three years are not to be expected. As noted in the definition of the activities of the committee, the work may consist in some cases merely of collation of existing data and putting them in usable form, rather than of original research.

Discussion on "Solenoid and Electromagnet Windings" (Hedges), Los Angeles, Cal., May 18, 1915. (See Proceedings for November, 1915.)

(Subject to final revision for the Transactions.)

V. S. Foster: The author mentions the fact that formula (**10**), for determining the correct size of wire, usually yields a result which does not exactly coincide with any of the commercial sizes, and recommends that in such a case the next larger size be used.

In some applications this procedure would hardly be permissible. For example, if the problem in hand were the design of field coils for a continuous duty shunt motor and if the ideal size of wire lay midway between two commercial sizes, the discrepancy between the number of ampere-turns desired and the number actually obtained by the use of the next size larger wire would be about 13 per cent. This means that the motor speed would be somewhere between 5 per cent and 10 per cent low and, moreover, for a specified temperature rise the field coils would contain about 28 per cent more copper than would be necessary if the ideal size of wire were obtainable.

Therefore, in connection with this paper it would seem worth while to mention the expedient adopted by certain manufacturers, whereby the equivalent of a special size of wire is obtained by the use of two standard sizes in series. Where the solution described in the paper gives a winding consisting of N turns of a special size, of circular mil cross-section M, and this special size lies between two standard sizes, M_l and M_s (larger and smaller, respectively), the procedure is as follows.

The equivalent winding consists of N_l turns of the larger wire connected in series with N_s turns of the smaller, N_l and N_s being determined from the relationship:

$$N_l = N \frac{M - M_s}{M_l - M_s} \text{ and } N_s = N \frac{M_l - M}{M_l - M_s}$$

It is customary to wind the larger size wire on the coil first and thus give the smaller wire the benefit of the better radiation associated with the outer surface of the coil. Under these circumstances the combination will have practically the same characteristics as a winding composed of the same total number of turns of the ideal size of wire, and the advantage much more than compensates for the slight inconvenience of dealing with two sizes of wire and making the joint during the winding operation.

Also, in connection with formula (**10**) it seems somewhat more logical to express the size of wire in terms of circular mils cross-section rather than in ohms resistance per foot. To this end the formula could be modified to read:

$$M = \frac{\pi \times 10.575}{12} \times \frac{D}{E} \times NI$$

which shows that the cross-section of the wire varies directly with the required number of ampere-turns and the mean length of turn, and also inversely with the voltage on which the coil is to be used. By the aid of an ordinary wire table the equivalent combination of two commercial sizes can then be derived as indicated above.

DISCUSSION ON "EXPERIMENTAL RESEARCHES ON SKIN EFFECT IN CONDUCTORS," (KENNELLY, LAWS AND PIERCE), SAN FRANCISCO, CAL., SEPT. 16, 1915. (SEE PROCEEDINGS FOR AUGUST, 1915).

(Subject to final revision for the Transactions.)

H. B. Dwight (by letter): In the discussion of the measurement of the skin effect resistance ratio of copper strips, spaced at 60 cm., it is stated that the large discrepancies between the theory for infinite strips, and the observations made, are believed to be due to power being dissipated by eddy currents. All distortions of current connected with skin effect may be called eddy currents, but where the conductors are far apart and carry sine wave currents, the distortions of current are regular, and this case of skin effect obeys very similar laws to those governing round conductors.

In the case under discussion, formula (**103**) of the paper is used, which takes into account only the crowding of current, due to skin effect, toward the flat surface of the copper strips. A more important action is the crowding of current toward the edges of the strip, and this accounts for practically all of the skin effect observed at 60 cm. spacing.

If the thickness of the strip is considered to diminish indefinitely, but the conductivity to increase so that the total resistance of the strip remains the same, then the only action is a crowding of current toward the edges of the strip. For this case, the skin effect resistance ratio can be shown mathematically to be the same as that of a round copper wire of 3/8 times the resistance of the strip considered. Figs. 14 and 15 of the paper show that such a formula is inapplicable to strips of appreciable thickness since it gives ratios that are too large. However, it is possibly a closer calculation than the formula for infinite strip used, and it tends to show that if the ratios were calculated by formulas applicable to strips of finite dimensions, the theory would probably check the test results of Table VII as closely as the computed ratios check the tested ratios for round wire given in Table III.

Compact engineering formulas for skin effect of uniform round non-magnetic conductors at commercial frequencies may be expressed in terms of the resistance of the conductor. Thus,

$$\frac{R_{ac}}{R_{dc}} = 1 + \frac{11.03}{(1000\,R_{dc})^2} - \frac{100}{(1000\,R_{dc})^4} \text{ for 60 cycles,}$$

and

$$\frac{R_{ac}}{R_{dc}} = 1 + \frac{1.91}{(1000\,R_{dc})^2} - \frac{3}{(1000\,R_{dc})^4} \text{ for 25 cycles,}$$

where R_{dc} is the resistance of the conductor to direct current in ohms per 1000 ft. These formulas are applicable to **wire**

or cable, of copper or aluminum, and for sizes of conductors up to 1½-in. diameter.

J. E. Clem: Although Dr. Kennelly does not discuss the skin effect of conductors located within a-c. machinery, it is worth while to mention the fact that the increase in copper loss in conductors within machines due to current distortion is very much larger than in cables or busbars, on account of what Dr. Kennelly terms "proximity effect." This is due to the fact that within machines a large number of conductors carrying currents at high density are placed in very close proximity to each other and as a result the magnetic field traversing the copper is of considerable value. In generators and transformers this is especially true. In fact, in many cases, unless special precautions are taken in design, the copper loss may be increased 20, 30, or even 50 per cent at 25 or 60 cycles on account of this "proximity effect." Occurring at normal frequency, it is evident that within machines this phenomenon is of the utmost importance to the designer.

The distribution of the flux in a conductor in a machine is very different from the distribution of flux in a conductor in air. In a conductor in air the flux forms cylinders or flattened cylinders around the conductor, depending upon whether the conductor is a round wire or a strip. See Fig. 11 of paper. In machines the presence of iron usually causes the flux to traverse the conductor in approximately straight lines, the flux density increasing from one side of the conductor to the other. This case corresponds approximately to that shown in Fig. 12.

While the cause of the extra loss due to the unequal distribution of current is the magnetic flux in both cases, the mathematical development should be different because of the different flux distribution. Mr. A. B. Field read a good paper on this subject in 1905 before the A. I. E. E., in which he developed a method of determining these losses.

L. P. Ferris: The results of most importance, seem to me to be those which apply to the skin-effect resistance-ratio. We are more interested in the increase of resistance of a conductor due to skin effect than we are in the slight increase in the internal inductance due to the same cause. The method by which the skin-effect resistance-ratio was determined experimentally is of considerable interest. The bridge was so arranged that this ratio could be determined by a few settings on a slide wire of the bridge. This is shown in Table II. The simple formula for the skin-effect resistance-ratio involves two functions which are proportional to the a-c. and d-c. resistances, but it is not necessary by the method used to determine the absolute magnitude of either resistance. The accuracy of these results, in so far as the resistance-ratio is concerned, should be very high, and this is shown to be true by the close agreement of the experimentally determined ratios

with those computed, in the cases where the "proximity effect" is small.

For the inductance-ratio it is necessary actually to determine the magnitude of the inductance at high frequency; the computed external inductance of the circuit, which does not change with the frequency, subtracted from the measured total inductance, leaves the value of the internal inductance which is compared with the computed internal inductance at zero frequency. As the change in inductance is only a small proportion of the total in non-magnetic materials such as were used in these tests, the precision with which the experimental results accord with the computed results is to be considered highly satisfactory.

There is indicated a very ingenious method of increasing the sensitivity of the telephone detector in a-c. bridge work at low frequencies. It is simply to place in series with the detector a telephone transmitter in front of which is a telephone receiver carrying an alternating current at, say, 700 cycles. This device causes a high-frequency variation in the low-frequency current passing through the detector when the bridge is out of balance. I have had occasion to try this device and found it very successful. The high-frequency effect greatly increases the ease and accuracy of the settings.

Discussion on "Arc Phenomena" (Collis), San Francisco, Cal., Sept. 16, 1915. (See Proceedings for September, 1915.)

(Subject to final revision for the Transactions.)

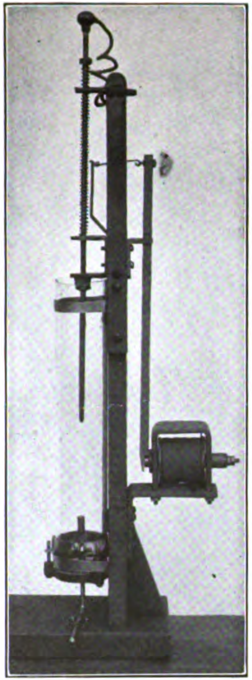
E. B. Merriam (by letter): Mr. Collis has given us some very interesting data concerning arcs as influenced by the shape of contacts in oil circuit breakers. It will be observed, however, that his results were obtained with comparatively small currents and moderate operating pressures, *i.e.*, 200 to 300 amperes at 6600 volts. Consequently, the arcs produced were comparable in magnitude with the contacts used and a very decided mutual influence should be expected.

In actual operation, however, little difficulty is encountered in interrupting circuits of this magnitude. It is only when the currents are from 10 to 100 times the values of Mr. Collis's tests that the circuit interrupting limits of the available breakers are reached. In connection herewith, we have made a large number of tests on high capacity circuits with currents of from 5000 to 20,000 amperes at 900 to 5000 volts, 25 and 60 cycles. These tests have indicated that the arcs are so large when compared with the size of the contacts that the shape of the contacts has little influence on the circuit interrupting capacity of the breaker. As a matter of fact, I doubt very much if a breaker rated at 10,000 kv-a. could have its contacts so modified as to increase its rupturing capacity to 15,000 kv-a. Consequently, I think Mr. Collis's results while of considerable interest are of academic value only and of but little assistance in practical design.

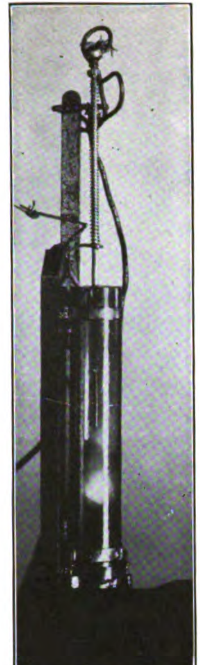
In discussing the contacts of oil circuit breakers, however, it must be remembered that their principal functions are to carry and interrupt currents. Their shape is influenced not so much by the circuit interrupting capacity of the breaker as it is by their ability to withstand burning and yet retain their current carrying properties under these conditions. It is assumed, of course, in this discussion that the breakers are provided with suitable burning or circuit interrupting contacts as in all modern designs. These are usually so arranged that they remove the arc from the current carrying contacts and protect them from the burning produced by an arc.

One point which is not mentioned is, however, I think of considerable importance. This is the influence of the medium in which the arc is immersed, on its shape. We have found that while in oil an arc will assume various shapes, some of which have been shown by Mr. Collis, that when an arc is immersed in a fluid such as carbon tetrachlorid or water, very different arc shapes are produced. Also we have found that the shape of the arc is greatly influenced by its proximity to the side walls or other boundary conditions encountered in the fluid container.

It may be interesting to record that as far back as 1902,



[MERRIAM]
FIG. 1—MINIATURE OIL CIRCUIT BREAKER



[MERRIAM]
FIG. 2—MINIATURE OIL CIRCUIT BREAKER INTERRUPTING 6000 VOLTS, 50 AMPERES, 0.45 POWER FACTOR

[MERRIAM]
FIG. 3—SUCCESSIVE STAGES OF ARC IN OIL CIRCUIT BREAKER

[MERRIAM]
FIG. 4—SUCCESSIVE STAGES IN OPENING OPERATION OF TYPE F FORM H-S BREAKER

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we investigated arcs under oil, observing their effects through transparent oil vessels. The first observations were visual ones made by means of a telescope. Later, Mr. Lichtenberg made a very interesting photographic study of transient arcs in oil. He developed and used a miniature oil circuit breaker, one model of which is shown in Fig. 1. This has a glass tube oil vessel and a moving contact, spring actuated, which moves upward when interrupting the circuit. The earliest pictures were taken about four years ago with an ordinary camera. A representative result, illustrated in Fig. 2, shows the arc formed when a 6000-volt, 25-cycle circuit carrying about 50 amperes at 0.45 power factor is being interrupted. The arcs, of which this is a sample, lasted about one-half cycle. Nevertheless, he has recently been able to obtain a number of successive pictures of these arcs illustrating their formation, expansion and extinction. One such record showing six stages of an arc is illustrated in Fig. 3, while Fig. 4 shows a similar analysis of the opening operation of a type F form H-3 oil circuit breaker.

The method of force measurement described by Mr. Collis and illustrated in Fig. 11 of his paper has been used by various investigators for some time. It is open to the serious objection, however, that it indicates the pressure or force at a point remote from the arc without in any way giving a clue to the pressures in the neighborhood of the arc. It is becoming recognized more fully every day in this connection that arcs produced in oil while interrupting a circuit represent a form of transient phenomenon having a very intricate mechanism. We do know that the amplitude of the pressure wave created by the arc is transmitted through the oil at a very rapidly diminishing pressure rate but the results reported give no idea of this rate. Some tests which we have made indicate that the pressures in the neighborhood of the arc are of the order of 5000 or 6000 lb., while the maximum pressures recorded near the walls of the container have been of the order of 500 lb.

Speaking of force distribution in an oil circuit breaker, I cannot quite agree with Mr. Collis's observations regarding switch bursts. We have found that the bottoms, as well as all four sides, of rectangular oil vessels will be distended as a result of the forces produced by the interruption of a circuit. This would seem to indicate that the pressures produced by an arc are approximately equal in all directions. I cannot but think that Mr. Collis has failed in his analysis to take into account the customary design of rectangular oil vessels for oil circuit breakers.

In the usual design of triple-pole oil circuit breakers, the oil vessels are rectangular having sides approximately equal. Those parallel to the plane of current flow are usually provided with fastenings for attaching the oil vessel to the frame, while those perpendicular to the current flow are not so reinforced.

It is perfectly natural in this case, therefore, that the sides perpendicular to the current flow being structurally weaker than the sides parallel thereto should be the first to give evidence of distress. It has been our experience, though, that too much stress should not be laid on the results of switch bursts or failures which occur under operating conditions since usually some point of importance in the operation of the device is not available for examination at a time following such failure. In addition, the mechanical design of the vessel has considerable bearing on its performance under abnormal conditions.

Mr. Collis refers to the increased resistance to breakdown which gases impose at high pressures, which leads us to believe that this phenomenon is of assistance during circuit interruption under oil. As a matter of fact in an oil circuit breaker, we are concerned principally with arcs, *i.e.*, with ionized gases which behave very differently from gases in which there are but few free ions. It will be interesting to learn more about the properties of gases under pressure, arcs in oil and the vacuum created by an arc. These points, if adequately explained, will go a long way toward solving the problems in hand.

No data are presented by Mr. Collis to substantiate his claim that rupturing arcs by a multiplicity of breaks or gaps, or by the addition of a shunted resistance, is not along the lines of correct development. Yet he states that a multiplicity of breaks increases the rapidity with which the circuit may be interrupted and for heavy duty switches is a necessity. It will be interesting to obtain the view of oil switch designers and experimenters and other interested individuals along this line of reasoning.

The speed of operation of an oil switch or circuit breaker is discussed by Mr. Collis. As I have previously pointed out, however, care must be taken in such discussions to distinguish between the so-called mechanical and electrical time of a switch. The so-called mechanical delay is the interval between the instant the overload relay, or trip, or other release actuating device of an oil circuit breaker is energized and the instant the oil circuit breaker contacts part. The so-called electrical time is the interval between the instant the contacts part and the instant the circuit is interrupted.

A better understanding of these intervals may be obtained from Fig. 5. The so-called mechanical delay would then be of the order of about 0.22 second, while the electrical time would be anything between zero and 0.33 second. The mechanical time may vary within wide limits, depending on the setting of the relay, the time delay of the mechanism and other operating details. The electrical time will vary through rather narrow limits, however, depending principally on the current, voltage and power factor of the circuit to be interrupted, the velocity with which the contacts part and the medium in which the arc is developed.

It is obvious from this explanation that Mr. Collis's quick-acting switch is one which has a short mechanical delay and that it will be called upon to open the circuit at a less favorable point of the current transient (see upper curve of Fig. 5) than one having a longer mechanical delay. Hence, a breaker with short mechanical delay will need to have a much larger circuit interrupting capacity than one having a long mechanical delay. This point has usually been cared for in the recommendations of American manufacturers but I have thought it advisable to again call attention to it as Mr. Collis's treatment may lead to a misunderstanding since we have a different meaning of the term quick-acting switch. We usually under-

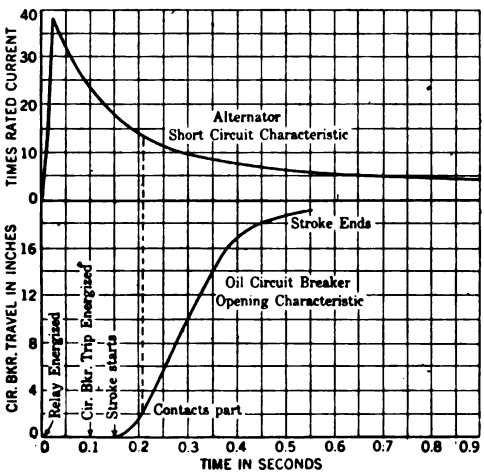


FIG. 5—ALTERNATOR SHORT-CIRCUIT CHARACTERISTIC AND OIL CIRCUIT BREAKER OPENING TIME CHARACTERISTIC

stand such a device to be one in which the electrical time is short, not the mechanical time.

So far as our experience goes, we find that no serious abnormal voltages are introduced into a circuit if the electrical time of the breaker is so short that it interrupts the circuit in not less than one-half cycle. Up to the present time, however, the mechanical difficulties encountered in making a suitable breaker mechanism so that a circuit will be interrupted in less than one-half cycle, even on a 25-cycle circuit, have been so great that the devices proposed are yet in an experimental stage. It is not, therefore, to be feared that any quick-acting circuit breaker now on the market, or likely to be introduced in the near future, will produce dangerously high pressure rises in the circuits to which they are connected.

In connection herewith, it is interesting to note that Mr.

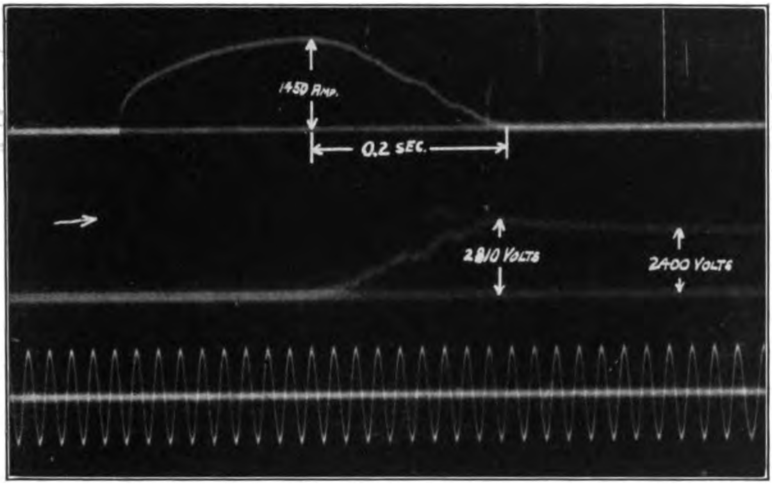
G. Faccioli presented a paper before the Institute about four years ago in which he gave oscillograms of pressure rises when various portions of high-pressure circuits were connected and disconnected from large power systems. These oscillograms will go far to substantiate the pressure rises observed by Mr. Collis by means of spark gaps.

On the last page of his paper, Mr. Collis mentions the watts dissipated by air-break and oil-break switches, hinting at a possible connection between the energy dissipated and the rating of the switch. It will be very interesting to learn more concerning the amount of energy dissipated in switches when interrupting circuits and its relation to the circuit interrupted. Also it will be instructive to know the relation between kilowatt rupturing capacity and the "compound unit volume" of a switch.

Chester Lichtenberg: Mr. Collis gives tables and records briefly descriptive of the circuit interrupting characteristics of several types of d-c. circuit breakers. The impression gained from them is that an oil-break switch will produce a lower pressure rise when interrupting a d-c. circuit than a magnetic blowout circuit breaker. This is contrary not only to the physical phenomena, which we believe to accompany the interruption of such a circuit by these two classes of devices, but is also in direct variance with the experiences we have gained from a large number of d-c. circuit interrupting tests with various kinds of breakers.

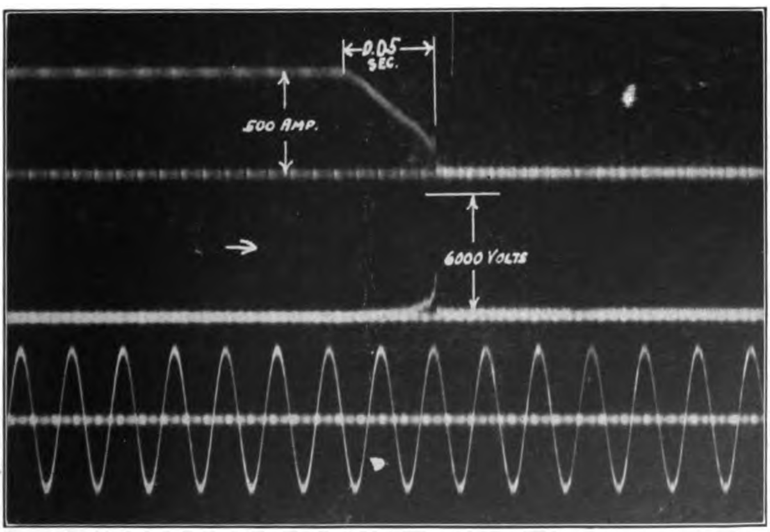
Consider a magnetic blow-out circuit breaker such as ordinarily used on power circuits. It will usually have a series blow-out coil whose electrical dimensions are small compared with the electrical dimensions of the circuit to which it is connected. Then during a circuit interruption, when the breaker contacts part and the magnetic blow-out coil is introduced into the circuit, there will be produced no appreciable alteration in the current. Also, since the magnetic circuit of the breaker has an air gap of high reluctance when compared to the rest of the magnetic circuit of the breaker, the magnetic field will be quickly formed. This field acts to distend the arc and produce a diminution in the circuit current by increasing its resistance. At first, the effect of the blow-out is strong since the current is high and the resulting field intense. As the circuit current diminishes, however, the blow-out field diminishes in intensity and coincidentally the blow-out effect is reduced until at the end of the cycle, the arc is gradually extinguished.

Now, consider an oil circuit breaker interrupting a d-c. circuit. When the contacts part, an arc is formed. This acts on the oil and gasifies it, producing a relatively high pressure in the immediate vicinity of the contacts. The gaseous body, being initially equally resisted in all directions, assumes a spherical shape as indicated by the photographs discussed by Mr. Merriam. This shape is retained until, through ex-



[LICHTENBERG]

Fig. 6—Oscillogram of Magnetic Blow-out Circuit Breaker Interrupting Inductive Direct-Current Circuit



[LICHTENBERG]

Fig. 7—Oscillogram of Oil Circuit Breaker Interrupting Inductive Direct-Current Circuit

pansion, unequal external pressures are exerted on the gaseous body by the walls, or barriers, or other parts of the containing vessel. Then the gaseous body shape changes and finally it breaks, resulting in an explosion which extinguishes the arc.

The effects on the circuits when these two types of circuit breakers are used to interrupt an inductive d-c. circuit are shown by the two representative oscillograms reproduced as Fig. 6 and 7. The magnetic blow-out circuit breaker record, Fig. 6, is that of the interruption of an inductive d-c. circuit carrying 1450 amperes at 2400 volts. The circuit breaker had a series coil which was connected in the circuit by the parting of the circuit breaker contacts. It is seen that the arc lasted 0.20 second and that at its extinguishment a pressure rise of 410 volts, *i.e.*, 17 per cent of the line pressure, was produced in the circuit. The oil circuit breaker record, Fig. 7, is that of the interruption of an inductive d-c. circuit carrying 500 amperes at 550 volts. The arc lasted 0.05 second and at its extinguishment a pressure rise of 5500 volts, *i.e.*, 1000 per cent of the line pressure, was produced in the circuit.

The two oscillograms shown are representative of several thousand tests. It is seen therefrom that when a magnetic blowout circuit breaker interrupts a circuit, the current seems to diminish rapidly at first and then more slowly until it is gradually reduced to zero. When an oil circuit breaker opens a d-c. circuit, however, the current is diminished with increased rapidity until at the end, it is suddenly reduced to zero very rapidly.

Mr. Collis leads one to conclude that the magnetic blow-out circuit breaker with a strong magnetic field produces a *lower pressure rise* than one with a weak magnetic blowout field. This reasoning is based on tests given in Mr. Collis's book on "High and Low-Tension Switchgear Design" but seems to be neither clear nor comprehensive.

Our experiences have indicated quite contrary results to those cited by Mr. Collis. This may be because all the factors in the operation of a magnetic blow-out circuit breaker have not been considered by him. One of these is that the electrical dimensions of the usual magnetic blow-out circuit breaker are small compared with the electrical dimensions of the circuit which it is interrupting. Another of these factors is the variation of performance with current.

If we subject a magnetic blow-out circuit breaker to a series of tests at constant pressure but gradually increasing currents, we find four distinct zones of operation. At relatively low currents, the circuit is interrupted slowly and the arc is of a "flary" nature. With larger currents, the circuit is interrupted more quickly and the arc is "snappy," the circuit interruption being accompanied by a sharp report. At still larger currents, the circuit interruption is still more rapid but the arc tends to hang and its extinguishment is accompanied by a "tearing" noise. If the current is still further increased,

a point will be found at which the arc holds and the circuit is not interrupted. This indicates that with small currents, the effect of the magnetic blow-out is small. With larger currents, it becomes more effective until a point is reached where the volume of the arc increases more rapidly than the blow-out effect and the arc holds.

Ford W. Harris: We are at the present time seeking light by which to design oil switches. Mr. Collis presents this paper based largely on tests of 200 and 300 amperes at 6600 volts. The very poorest and cheapest of oil switches will open many times this current without injury. In fact switches of the type illustrated will safely open at least ten times this current. Just what value tests of this magnitude, or results or conclusions, based on such tests, may have, does not appear.

The photographs of arcs in oil switches differ from any that I have ever seen, and are entirely at variance with all the tests which I have ever made. For example, Fig. 5 of the paper, which I understand is a photograph of the opening of the switch shown in Fig. 6, is most amazing. We have ordinarily put the "trailing pieces" on switches to take the final arc, and we find that even on very heavy overloads no arcing takes place between the main contacts which are shunted by the trailing pieces until the main contacts have fully opened. Yet Fig. 5 shows an astonishingly even arc all over these contacts following the contour as evenly as if it were traced on the side of the tank by a master draftsman.

Mr. Collis's remarks and figures as to pressures are equally surprising. For example he shows that in Fig. 1 with a 200-ampere, 6600-volt arc a pressure of 70 lb. per sq. in. was registered 2½ in. from the arc. This pressure is many times that observed on real short circuits of say 5000 amperes, and I feel that there must be some error. Any such pressure would undoubtedly tear out the thin metal sides of the cheaper forms of oil switch like so much tissue paper. Yet these switches in daily service open currents of many times 200 amperes at 6600 volts without even throwing oil.

Mr. Collis should state briefly his reasons for believing the following statements to be true.

(a) "The larger the lateral size of the contact the greater the effects of the explosion will be felt." To my mind it is hard to conceive how the shape of a contact can govern the transmission of pressure through a liquid medium.

(b) "The volatilization of the oil and its quiescency is of importance in destroying a vacuum created by an arc." Just what is meant by the quiescency of the oil, and how does an arc form a vacuum?

(c) "Rupturing the arc by a series of gaps and resistances does not appear to be the correct line of development, as apart from the increased size of the switch and the relative merits

of sustained arcs the creation of a number of coreless vortices defeats the primary object of the switch designer." How are the coreless vortices formed, what harm do they do, and how do they defeat the object of the designer?

(d) " Fig. 9 illustrates the large amount of gas force exposed to the oil." What is gas force, and how is it exposed to the oil?

(e) " Academically it (kw. capacity) is understood to mean the compound unit volume of a switch." What is the compound unit volume of a switch, and how is it related to kw. capacity? In our usual practise in this country we do not rate an oil switch solely on its cubical contents, as we think that the speed of break, and other considerations, enter into the value of this term. Where is the term so "academically understood"?

Mr. Collis's oscillograms, Figs. 15, 16, and 17, are representative of many tests on heavy currents. The method of connection shown in Fig. 18 is not, however, the most convenient one, as the potential element of the oscillograph is connected directly to the generator terminals. A better method is to connect one terminal of the potential element to the line terminal of the pole of the switch to be tested. In this way the opening of that pole will cut off the voltage wave *if that particular peak opens the circuit.* If the circuit is opened prematurely somewhere else the current wave ceases before the voltage wave. This method of connection is standard in such tests in this country.

Considering the oscillograph records, Figs. 15, 16, and 17, in Mr. Collis's paper, it may be said that these are fairly representative of the conditions under which a circuit breaker opens. It is evident from inspection of these records that the events recorded on the left hand side of the record occurred first. This is shown by a sharp drop on the heavy line which represents the voltage curve, this drop being due to the sudden application of heavy current. It is also evident from the fact that the current line rises very sharply to meet the normal curve of the current which thereafter follows. It is also evident from the fact that the current gradually decreased thereafter, this decrease being due to a gradual dying down of the current as observed in many tests of this kind. It is also evident from the small peak of the voltage wave at the instant the circuit is broken.

While these records show that the current wave resisted for seven alternations, five alternations, and five alternations respectively, it must not be supposed that the actual arc between the contacts held on for any such a length of time. It was, of course, necessary for the armature of the trip coil to move, for the latch of switch to be released, and for the mechanism of the switch to move sufficiently to separate the contacts before any actual arcing between the contacts took

place. As a matter of fact in switches of this type operating on currents of about the magnitude shown in these records, it has been found that the actual duration of the arc between the contacts is practically always less than one alternation. On heavier voltages, or in cases where the switch was seriously injured on such tests, the current has been observed to hold over, but in successful tests at 11,000 volts and below, the first current alternation after the arc starts is the last. This may be regarded as normal operation. In other words the first six alternations of the current wave in Fig. 15 represents the time taken by the switch in getting under way, and a portion of the last alternation shown at the right-hand side of the negative, and above the zero line, represents the actual duration of the arc in the switch.

Careful measurements of the voltage of arcs across the contacts at the instant of opening show that such arcs are of quite low voltage, and that they terminate practically at the current zero line.

Unfortunately the peaks of the current waves in most of Mr. Collis's records go off the film so that it is impossible to exactly place them. Many tests made by the writer indicate, however, that the last wave on which the break takes place is rarely materially lower than would be expected from the natural decrease of the current. In other words the resistance of the arc under the oil is not sufficient to materially alter the height of the current wave above the zero line. This is very different from the conditions found where air-break switches open direct currents. In a gravity-accelerated oil switch the switch contacts in a single alternation can move only a very short distance, probably less than ¼ in., and one would not expect an arc of 2300 amperes, and ¼ in. in length, to have any material resistance.

It is to be noted that the current in the records shown in this paper ceases absolutely at the zero line, this also being the case in oscillograph records of each test which the writer has examined. It is evident that the arc is holding over strongly as the current values approach zero, and it is evident that as the current values seek to cross the zero line something happens that makes it impossible for the current to reverse its direction. The writer cannot conceive that this is any physical movement of the oil. In other words when the curve reaches the zero line a very heavy arc acting on a hydrocarbon oil produces a considerable pressure thereon. The writer cannot believe that, in the small fraction of a second that it takes for the current to cross the zero line, this pressure can decrease to zero or below, and that the surrounding oil can be accelerated and projected into the arc area to a sufficient degree to produce any material change in the conditions in that area.

It is my personal opinion that what has occurred is this: The heavy arc has been drawn through a hydrocarbon oil

and the intense heat thereof has vaporized a portion of the oil producing a hydrocarbon vapor, and very possibly free hydrogen. These hydrocarbon vapors are mixed with metallic vapors, the arc path consisting of a mixture of hydrocarbon and metallic vapors. In any ordinary current the proportion of hydrocarbon vapors is probably far in excess of the metallic vapors. The gases in the arc path must act as a rectifier, that is they resist reversal.

In all his examinations of oscillograph records of heavy short-circuit tests made at voltages below 11,000 volts, the writer has never seen a record of a successful switch opening in which the arc has held for more than one alternation. In other words where the switch has successfully opened the circuit, it has done it in one alternation of the arc.

To determine these facts it is, of course, necessary to use refinements of testing not disclosed in Mr. Collis's paper. For example, it is necessary to use several oscillograph elements, taking voltage reading across the break, another beyond the break, and one at the machine terminals. It is also desirable to take the current in more than one phase, and preferably in all three phases. The writer has also found it very desirable to provide auxiliary contacts on the switch mechanism so that the exact degree of separation of the contacts can be determined by the oscillograph at any point on the current or voltage waves.

Summing up the writer's view of the case, it may be said that an oil switch does not open the circuit by any quenching or cooling action of the oil itself. The arc is drawn through a hole in the oil which is filled with hydrocarbon and metallic vapors, and the nature of this arc is such that normally no reversal of current is possible. So far as I am aware this is a new theory of oil switch action. While it is entirely possible that I am in error in this connection, I believe this theory to be supported by the many experiments and tests which I have analyzed, many of which have been published.

W. D. Peaslee: I feel that there is a little divergence of view in the paper and discussion as presented. Consider these pressures, for instance, which Mr. Collis gives, of 70, 63, 61, 78, etc., and some mentioned in discussions going to 5000 lb. If you take a charge of gun cotton and explode it in a large body of water, you will get low pressure under certain conditions. If you then explode the gun cotton in a steel case you will get high pressure. As to the form of switch where the arc is thrown out through a series of baffles, it has been my understanding from conversations and arguments with the manufacturers of that switch, especially in connection with competition on commercial bids, that the arc is blown out violently by the cannon-like action of the arc gases blowing through these holes and flowing around the baffles, and that the arc is confined in a large steel case for the purpose of generating these high pressures.

The pressures given by Mr. Collis are obtained in a free body of oil and are simply a measure of the diffusion of the traveling wave of force through a free body of oil. As to the 6600-volt, hand-controlled switch, if you take that and fill it with oil, so there is no air in it, and create an arc in that switch, you would find that the same pressures appear. You will have high pressures in any confined space in which explosions take place, but we all know the oil switch is not built that way. The ordinary small capacity oil switch of 6600 volts, 200 amperes, is built with a free body of oil, and the wave of force which goes out dissipates itself very largely in the boiling. I remember back in 1907 opening some of the old type of oil switches we have here on the Pacific Coast, and opening them on short circuits of 66,000 volts. I know that the oil went up around the ceiling and the top of the oil switch went up and all sorts of things happened. There was not much force there, probably not more than 400 or 500 lb. per sq. in., but if the switch had been confined in a steel case there would have been very high pressure.

As to the multiplicity of breaks, I think that the various discussers and the author are considering the matter from entirely different viewpoints.

As to quick-acting switches Mr. Collis says: "In comparison, a quick-acting switch must have a greater rupturing capacity than those of the slow type, their rates being, within limits, proportional to their time elements." We have had a long discussion, and at the end of it I think only one of the discussers missed quoting that sentence, stating that without the aid of a diagram it is difficult to understand. I think the apparent variations in the discussions are due to the fact that we are not discussing the same thing.

In reference to the magnetic blow-out, I have done some oscillograph work on that myself, and I think the difference here is that a voltage rise may be on the line or across the switch. You will note that Mr. Collis says: "Apart from the time taken in opening the circuit the extra inductive rise is due to the separate coil for the production of a magnetic field. This coil is short-circuited when the breaker is in the closed position, but in series with the line when opening the circuit. As there is an appreciable time taken up in the building of this field, which is not at its greatest density when the arc is first formed, a choking effect is introduced and the resistance being low, the back e.m.f. assumes a high value, so that if the turns are doubled the induced e.m.f. is quadrupled, the current being one-fourth." I think that is simply another case of working on two different things, the discussers referring to one pressure rise, that on the line, and from my impression of the paper I think Mr. Collis's references are to the pressure rise across the switch.

Discussion on "Overhead Electrolysis and Porcelain Strain Insulators," (S. L. Foster), San Francisco, Cal., Sept. 17, 1915. (See Proceedings for August, 1915.)

(Subject to final revision for the Transactions.)

L. W. Webb: This wire (samples of copper-clad wire were exhibited) has been used on radio antenna on shipboard, and has proved entirely unsatisfactory for this use. It lasts from three months to a year maximum, and often not as long as three months. When once installed and not taken down it lasts the maximum length of time; but if disturbed after being installed the individual strands are found to be broken throughout the entire length, and the least twist or kink breaks the completed wire entirely. Where installed close to the smokestacks on vessels the escaping gases cause rapid deterioration, and cases have been noted where the wire lasted only about two or three weeks.

This wire being exposed to a salt air atmosphere in combination with the gases escaping from the smoke stack apparently causes a very active chemical compound and the rupture of the outer copper casing, as these samples show. There are evidences of both chemical and electrochemical action. The high-frequency currents circulating only in the outer skin of the copper enclosing jacket apparently produce small amounts of $2NO_2$ which in combination with H_2O would give HNO_2 plus HNO_3, nitrous plus nitric acid, the nitric acid attacking the copper jacket and destroying it, allowing electrochemical action between iron and copper and thus completing the destruction of the wire itself. Also, smokestack gases in combination with salt air, rain, etc., and the high-frequency discharges from antenna produce, it is believed, both HCL and HNO_3, both of which attack copper very virulently. Under certain circumstances it is believed it is possible to produce sulphuric acid also, but the action of nitric acid is believed to be the most plausible of all.

The copper-clad wire is the only one ever used, as far as I know, that proved utterly unsatisfactory in such a short time. Before trying this copper-clad wire we used a wire made up of seven strands of 20 B & S silicon bronze wire and experienced very little trouble due to corrosion. The wire would, however, kink very readily, and when kinked would often break, but when properly handled no trouble was experienced. Since trying the copper-clad wire we are again using this silicon bronze wire.

L. Addicks: I think Mr. Webb's trouble in the case of the copper-clad wire due to the nitrogen of the atmosphere being oxidized by the discharge of the radio antenna, which pits the copper, causing galvanic action with a salt solution for an electrolyte. The cell with an iron anode and copper cathode will very rapidly corrode the former. The problem is different from that presented in Mr. Foster's paper, where we have no high voltages to deal with; but it seems that salt is largely the offender in furnishing the electrolyte.

I had intended to ask Mr. Foster why we could not calorize some of these connections with the idea of having aluminum in circuit to act as an anode. This would oppose the passage of any current, just as it does in the rectifier, but I am afraid, in the presence of the salt fog, the aluminum itself would be attacked by the chlorine, and that leaves us worse off than before. I suppose this salt fog is really ocean spray with considerable chlorine in it. I clipped from a newspaper the other day a reporter's view of this action:

" The disintegrating action of electrolysis from the electricity in salt water and salt air has given yachtsmen a good deal of trouble of various kinds. Aluminum utensils for example, were much used for a time in the table service of yachts, as they were light, stood rough wear, and looked almost as well as silver. But it was presently discovered that overnight they became covered with a fine powder due to the action of the electricity in the salt air."

S. L. Foster: We have not had much experience with aluminum in this city because when tried twelve years ago on a small scale near the Golden Gate it proved unsatisfactory in the salt foggy exposure. There was some small-sized bare solid aluminum wire put up around the cliff by the telephone company as an experiment. It broke after being up only a few weeks. Upon examination it was found that this wire was badly tarnished and broke off upon bending once 90 deg. between the fingers. It had become brittle since its exposure. This tarnishing was probably due to the action of the chlorine content of the salt in the ocean spray.

Speaking of the copper-clad wire, I would state that under the same conditions it went about as fast as the aluminum. The electric battery action appeared here. I assume that the electrolyte was hydrochloric acid formed from the chlorine in the salt moisture. It was probably not nitric acid as there would not be enough stray voltage from a telephone line to produce nitric acid from the atmosphere. The iron salt formed burst the copper covering open before the wire broke. You could see this progressive action very clearly—splitting off the copper sheath both ways from various centers. Lead-covered cables and insulated copper wire are now used in this exposed district.

The manufacture of copper-clad wire has been abandoned, I understand.

Bare copper exposed near the ocean becomes covered with a greenish salt which I have assumed to be the oxy-chloride of copper. By others it has been called the carbonate of copper. I know of no analysis having been made of this salt.

John B. Fisken: I had occasion not long ago to look up the life of guy wires over railroad tracks in connection with some rules that were being made up. I found that ordinary galvanized cables that had been up many years over a railroad crossing were absolutely in as good condition as when put up. The tensile

strength was just as high, but I found that some of the span wires supporting the trolley wires, apparently of the same material, had a very short life. Where I come from we are something like 300 miles from the sea, and at an elevation of 1900 feet, so, of course, there is no salt fog. The reason for this trouble I could not discover anywhere, but in reading Mr. Foster's paper I concluded I probably had the solution of it. I presume that the smoke from the locomotives formed on the insulators would allow this leakage Mr. Foster speaks of, and the electrolytic effect of the direct currents on this wire is probably causing that wire to have such a very short life. I propose, when I go back home, to do a little painting or treating span wires with oil to find out if that is the reason.

S. L. Foster: In response to what Mr. Fisken spoke of, I would advise him instead of painting the spans to put in longer insulators. The action referred to is probably due to the formation of sulphuric acid from coal burned in the locomotives, and that emitted with the steam and smoke, would coat the insulator with an effective electrolyte to begin action.

John B. Fisken: The reason for the investigation was that very question—it was claimed that the sulphur contained in the coal would deteriorate the guy cables. We have to use galvanized steel for guy cables; under the rules referred to it would not be possible to use it for conductors, which we frequently have to put out on country roads. I have not had any analysis made of the smoke, but believe there is a large amount of sulphur in it; but it seems to me that would attack the guy wire as much as the span wire, which it does not seem to do. There must be an electrolytic effect somewhere.

John H. Finney: I do not know a great deal about Pacific Coast weather conditions and their effect on aluminum; but in the east, aluminum wire which has been up in perhaps the worst town in the east for atmospheric conditions, Charleston, South Carolina, has been up about 14 or 16 years, to my personal knowledge, and is in very good condition today. Apparently no change has taken place in the aluminum. The middle strand of the 7-strand cable is just as bright as the day it was put up. I appreciate that west coast conditions are not identical with the eastern conditions; they have not so much fog in Charleston, but have very bad atmospheric conditions, a heavily-laden salt atmosphere from the sea, and at times extremely dry heat. Other material on the railway line corrodes and goes to pieces rapidly. I am not defending aluminum when erected under wrong conditions, and perhaps our eastern conditions are radically different from western conditions. There is a great deal of aluminum up on the Pacific Coast, of course, and I presume most of it is in satisfactory condition; certainly many of the big plants in California and elsewhere along the coast testify to its good qualities as long-distance transmission material.

L. Addicks: Is it not a fact that the aluminum Mr. Finney

refers to as in use a long time is on high-tension transmission, where great care is taken to avoid a leakage condition?

J. H. Finney: That is true, there is practically no leakage.

T. M. Stateler: I would ask if there is any particular leakage from the concrete poles of the San Francisco Municipal Railway?

Paul L. Ost: We have not had any concrete poles in service a sufficient length of time to give us any real data upon them. However, we have had some experience in a certain class of construction very similar to that which Mr. Foster described. Out at our beach terminus, where we go within 200 feet of the beach, we have had occasion within the last six months to take down a portion of the construction which was up eighteen months only. Where the strand wire was met by our own porcelain insulators we found all of the galvanizing was gone, and in most instances at least half of the strand wire had been eaten away. We had one particular case of a feeder span, where the copper was badly eroded close to the insulator. This loss of the galvanizing of the strand wire itself does not extend back any great distance from the insulator, possibly not over an inch at the most, which would indicate to my mind that it is an electrolytic action which is confined to the points where the current leaves the wire.

I might also add that we have had an experience in this same neighborhood, with fire alarm conductors, which are weatherproofed copper. The wire was badly eaten off at the point where the tie wires are attached to the main line. I think possibly this was also due to the electrolytic action where the current leaves and goes down from the insulator. A potential in those cases would not possibly exceed 50 volts between the wire and the ground.

DISCUSSION ON "THE COMBINED OPERATION OF STEAM AND HYDRAULIC POWER IN THE PENNSYLVANIA WATER AND POWER COMPANY SYSTEM" (WALLS), AND "SUPPLEMENTAL POWER FOR HYDROELECTRIC SYSTEMS" (VAUGHAN), PHILADELPHIA, PA., OCTOBER 11, 1915. (SEE PROCEEDINGS FOR OCTOBER, 1915).

(*Subject to final revision for the Transactions.*)

A. S. Loizeaux: The Consolidated Gas, Electric Light and Power Company of Baltimore began taking power from the Pennsylvania Water and Power Company on October 1st, 1910, the contract calling for delivery of not less than 70 million kw-hr. during the first year, with the demand of 13,333 kw. That figure is obtained by taking two-thirds of the peak load on the station, which was 20 thousand at that time. The contract provided for an increase of energy in following years, but not to exceed 105 million kw-hr. per year. A demon-

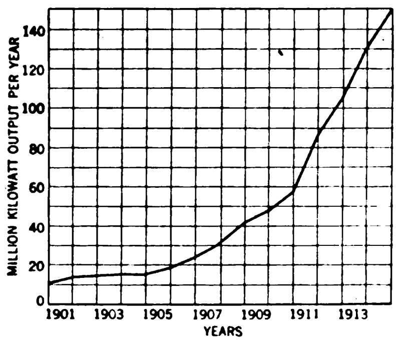


FIG. 1—INCREASE IN OUTPUT FOR YEARS 1901-1915
TOTAL GENERATED AND PURCHASED

stration of the effect which Mr. Walls notes, that the development of water power exceeded the original contract provisions, is found in the fact that the consumption of the gas and electric company for 1915 will be about 165 million kw-hr., a quantity 57 per cent greater than the maximum originally provided for.

The growth of the company's load has been very rapid since water power was available. Fig. 1 indicates that at that time a very rapid upward tendency was taken by the curve, which has continued ever since, so that in the five years since we began taking water power we have over two and one half times as great an output as the total output at that time. In other words, the company's load to-day is 250 per cent of what it was in 1910.

It will be seen that from the year 1910, when water power was first purchased, the growth has been much more rapid than before that date. This is accounted for by the fact that when large blocks of energy are available for sale without ad-

ditional capital outlay it is possible for the industrial power sales department to go after and procure such customers, who would not be procured if an addition to the generating station was first necessary.

Mr. Walls gives a clear statement of the great advantages to be secured by cooperative measures on the part of a water power plant and its customers operating steam plants. This cooperation is vital to the success of the hydro plant in nearly all cases. The hydroelectric development is rare indeed that does not have to use steam auxiliaries for its maximum economical development.

It is sometimes difficult to justify the initial purchase of water power at usual rates by a system fully equipped with steam apparatus to carry its peak load; because fixed charges cannot be decreased, and operating costs only partly avoided by the use of water power. This condition changes, however, as soon as increased load is obtained, when the use of water power makes it unnecessary to invest capital in additional steam equipment. It has been the experience in several cities that when hydro power has been available contracts for large blocks of power have been closed, and the selling of energy greatly stimulated, thus creating a market for the available energy without increasing the capital investment of the central station.

Standby Operation. As Mr. Walls has stated, standby operation is more necessary in the early days of a hydro plant than after conditions become settled. In Baltimore we kept a turbine running in the early stages of the use of water power; but for several years it has been found unnecessary to keep any generators on the bus for this purpose. A limited number of boilers are kept banked to carry the more important a-c. service in the event of interruption to water power.

When an electric storm occurs generators are started and carry load until all danger of interruption is over. The d-c. distribution system is protected by storage battery.

Several years ago oil burning equipment was installed to be used for emergency operation. It was found, however, to have drawbacks in operating, as well as cost, and the same or better results in quick steam generation have been obtained by the use of mechanical stokers and forced draft.

Operating Conditions at High and Low Water Stages. It is interesting to note the reversal of operating conditions in periods of plentiful water compared with low water periods.

When water is plentiful the hydro plant takes all available load up to its capacity in generating units. Mr. Vaughan mentioned this as existing in different plants. As I have said, when water is plentiful the hydro plant will take all available load up to its capacity in generating units, provided the load is available. This is shown in Fig. 2 of Mr. Walls's paper. If there are peaks in the total load which are

higher than the generating capacity of the hydro plant, these peaks are taken by steam units which thus supply the necessary capacity with a small consumption of fuel, due to the short hour operation. Such peaks are shown above line "R" in Fig. 2 of Mr. Walls's paper.

When water is low a reversed condition is obtained. The steam plants then operate 24 hr. per day at a high load factor, generating as much energy as is represented by the deficiency of water power at the time, as shown in Mr. Walls's paper under the steam load line. The hydro plant carries the peaks, being able to store water 24 hours or more and deliver its energy at such times as is called for by the load curve, over the horizontal line representing steam generator capacity in service. This gives an ideal steam operating condition, and a low cost for energy generated, while the water available is used with maximum effect.

Character of Contracts. In contracts to provide for maximum cooperation between hydroelectric systems and purchasers, it will usually be desirable, instead of using a rate for energy and then charging for demand, which is the usual system, to fix two rates for energy:

1. A primary rate based on the value of energy taken which can ordinarily be counted upon with regularity; and, (2), a secondary rate for energy which cannot be guaranteed but which is available except at times of low water flow.

It will be seen by analyzing conditions that when a hydro station has machine capacity much larger than the minimum river flow the hydro power is more valuable to the steam company than an increase in their steam equipment which could generate the same amount of energy during the 24 hours, or even with the prevailing load factor of the total load. The reason for this additional value is that in times of low water, when the minimum guaranteed power only is available, the steam plant can call for this energy on the peak. This energy would therefore be delivered at a very low load factor representing several times the capacity of equipment that would be required to generate this amount of energy at the usual load factor. For instance, 10,000 kw. water power for 24 hours per day is equivalent to 240,000 kw-hr. daily. If a 10,000-kw. steam turbine were installed it could generate this amount of energy but would be good for only 10,000 kw. on peak load. The water power plant, however, if it had, as is usually the case, more generating capacity than the minimum flow capacity, would be able to deliver 240,000 kw-hr. on peaks at 40 per cent or even 20 per cent load factor, equivalent respectively to 25,000 or 50,000 kw. capacity. It is evident that the energy delivered in this manner has a much higher value than the energy available from a 10,000-kw. unit, because it makes unnecessary the installation of 25,000 or 50,000 kw. in steam capacity.

This secondary rate should be based on the cost of fuel and operation in the steam plants. The operation including labor, superintendence, water, lubricants, station supplies, expense and maintenance on steam and electric equipment and buildings. It should not include fixed charges on investment. This is virtually the equivalent of the steam generating cost under whatever conditions may obtain. It will readily be seen that the demand charge under the plant conditions described would prohibit the method of operation described for low water periods, as illustrated by Fig. 4 of Mr. Walls's paper. The basic idea in the establishment of a secondary rate is that it is better to use water when it is available than to purchase coal and allow the water to waste. The profit resulting from such operation should, of course, be equitably divided between the producer and consumer.

Emergency Operation. The contract should be such that all possible help in time of emergency should be given to the party in trouble. It would be shortsighted to withhold any help within the power of either company during emergency because steam plants, as well as hydro plants, are subject to occasional collapses due to unforeseen and abnormal conditions. A break in a steam header or burn-out in main duct line will cripple a steam plant temporarily, while needle ice may shut down the hydro plant. In any such event all resources that can be commanded should be utilized to supply existing load.

Energy supplied during emergency conditions should be billed at the reasonable cost of meeting these conditions, which it may be impossible to specify in the contract except in these terms. The most frequent use of extraordinary power in the system under consideration has been energy generated at times of storms. This energy in most cases has not been actually necessary but was generated in order to have prime movers actually on the line in the event of trouble. The excess cost of such operation over the price paid for energy should be borne by the hydro plant.

It will be noted that the methods of cooperation recommended are practical means of carrying out conservation of water power, and therefore of coal. The electrical industry is committed to the principle of the conservation of our national resources. Leaders in the industry are cooperating with others in having the government make reasonable regulations encouraging instead of discouraging water power development, and it is a cause of much satisfaction to the engineer to be able to actually conserve either by the development of water power or by using hydroelectric power, when its use is attended with operating economies and benefits to his company.

It will be seen from these remarks that water power for at least a part of the systems' total load has real advantages to the steam central stations in reducing, first, peak loads; second, serving as reserve for emergency conditions; and,

third, what is more important, showing a profit in operation which increases as the load increases. This saving is largely in the nature of the limiting of capital invested.

The steam relay and the variable amount, in per cent, of the steam-relayed power, naturally depends upon the character of the load. No company could afford to take any chances with general power and lighting; they have to provide relay. When it comes to other classes, in Baltimore, for instance, there is a copper smelting company that refines copper electrically, with a load of over 6000 kw. continuous, and if their power is shut off it simply means that the power is not sold and some labor lost, but not a large labor loss in comparison with the value of the energy. Now, it would not pay to provide separate relay equipment for carrying that particular load. The electric load may or may not be of such a character as would pay for relay power. So that the nature of the load, whether it involves large amounts of labor or the convenience of the public, will determine how much relay power must be carried in each case.

Mr. Birkhinhine: I think the papers brought out by Mr. Walls and Mr. Vaughan gave a very clear idea of the economical limiting of water power development, which is a thing of prime importance in any project.

The Pennsylvania Power Company was not only selling power to whoever would buy, it was selling power to a man who wanted it and making that sale a return to the company buying up the load. I think the last unit installed was the third largest one since the plant was first in normal operation, and provision is still there for another. The practise is generally followed now, apparently, of leaving uncompleted space so that the structure can be continued and units put in when warranted.

In Mr. Vaughan's paper there was mentioned the supplemental capacity required for standby or for small annual output that is to be used to produce kw. capacity and not kw-hr. output. I want to ask Mr. Vaughan how he determined the value of steam as a base load, and in favor of water power as peak load, and so to get his answer I will take the opposite viewpoint. If on Fig. 3 beginning at 6 a.m. and running to 8 p.m., the steam plant carries 3000 kw. right straight across, there is a total of 42,000 kw-hr. by steam, which is spread over practically the same number of hours as in the curve originally shown, but it is uniformly low; in other words, on the steam plant for 14 hours, and the fluctuating loads and the peaks are carried on the water power. That is further brought out in Fig. 4, on the next page, by looking at the curve for the low water. There is a steam usage of about 2300 kw. and of course the peak on the water power is then between that and nine thousand.

Now applying a similar case, on the normal load curve,

the steam plant runs from about 3:45 until 8:15 on a load that builds up and then runs down again. If that had been a 2600-kw. steam output from one o'clock to nine o'clock there would also have been a 100 per cent load factor. These, of course, as Mr. Vaughan has said, are purely imaginary curves. Both papers bring out very clearly the special conditions that come into the enterprise, that is, instead of building a new plant, making the best use of plants that exist, and as Mr. Vaughan's paper says, in some cases practically obsolete machinery is found to be economically usable and can save money.

J. F. Vaughan: Mr. Loizeaux mentioned oil firing. The company spoken of in the first paper as using oil firing in standby work has had sufficiently satisfactory results to warrant their equipping a second plant with oil firing. In connection with the subject of quick firing, the method used by the Union Light and Power Company of St. Louis, who take the bulk of their power from Keokuk (the Mississippi River Power Company) is interesting. Before Mississippi river power was delivered a member of the St. Louis company expressed his doubt as to the reliability of transmitted power and the fear that they would have to maintain heavy standby expense to properly relay it. Since power has been delivered, however, he has expressed his gratification and confidence in it, and has become enthusiastic over a method of quick starting which he has developed. This method is keeping the water in certain of the boilers at about 212 deg. F., by a small heating boiler placed in the basement of the power house underneath the main boilers, and laying on the main grates a fire of carefully selected coal, interlaced with kindling and oily rags, all ready to light in emergency. He states that by this method he can pick up 15 thousand kw. of load in fifteen minutes.

As to water power taking the base or peak of the load, this depends, as both Mr. Loizeaux and Mr. Birkhinhine have pointed out, very largely on the shape of the load curve and on the character of the water power. It depends further on the investment in the supplemental plant and the fixed charges in such plant that must be charged against the water power.

In a number of the cases cited in New England the fixed charges on the steam plants are not chargeable to the water power, because they are on plants already existing whose charges are already carried in other ways. An interesting case of the cooperation between a water power plant and a steam plant in which existing steam investment in both water and steam plants is used to best advantage, is mentioned in the first paper as the 7th and 8th systems. The 7th system having 9000 kw. of water power, controlling a sufficient pondage to enable them to concentrate their output during low water within a portion of the day, in this way carries the peak of the load of the 8th system, which is connected to it on the other end of a transmission line.

The shortening of the hours of operation during low water enables such a water power plant to save labor by cutting out a shift of operatives. The arrangement between these two connected systems allows the steam plant to take advantage of the full pondage and storage capacity of the water power plant, and enables the water power plant to run at a very high load factor when there is plenty of water, saving coal on the steam-operated system.

Mr. Birkhinhine spoke of a steam plant operating to carry the base of the load. It is evident where the fixed charges of an existing steam plant do not come on the water power that the steam plant can be used to good advantage to carry either the peak of the water power load or a part of the hours of the daily duty of the water power, enabling the water power plant to save a shift.

In closing I wish to say that the papers and discussion have brought out clearly that the operation of steam plants as auxiliary to water power plants is more than a purely technical subject; it is possibly as much a problem for the contract agent as for the designing engineer. Nor can it receive too much attention from the operating management in organizing the operating force and in training the men in the emergency use of their auxiliary or supplementary capacity.

In recent years, as transmitted water power has become more reliable, the natural distrust of such service has diminished. Today it is the duty of the operating company to establish confidence, complete confidence by simplicity in contracts and agreements and straightforward, fair dealing.

We have produced reliability in the generation and delivery of power; now we want the same reliability in the developing and holding of our markets.

DISCUSSION ON "CONSTRUCTION ELEMENTS OF THE TALLULAH FALLS DEVELOPMENT" (ADSIT AND HAMMOND), PHILADELPHIA, PA., OCTOBER 11, 1915. (SEE PROCEEDINGS FOR OCTOBER, 1915.)

(Subject to final revision for the Transactions.)

A. J. Porskievies: I ask Mr. Adsit to tell us what type of rotor the generator has, and also whether there is any reactance protection from short circuit, and whether the generators are operated with the grounded neutral; and finally whether the efficiency of 95½ per cent on the generator includes friction.

A. S. Loizeaux: I would like to have the author explain the operation of the operating flashboard as detailed in Fig. 8.

A. J. Porskievies: It is a very extended transmission system in a country noted for thunder storms and I would be glad to have the author tell us about lightning troubles.

C. G. Adsit: I rather think this is a stronger rotor than is usually used with vertical steam turbines. The rotor is built of solid steel disks with the pole pieces dovetailed thereto. The pole pieces in addition to this support have steel end rings which are bolted to the outer end to sustain the winding. The rotor is also provided with fans on each end to promote a circulation of about 35,000 cu. ft. of air per min. It is my understanding that the efficiency of 96 per cent includes all friction and the blowing of air for the generator ventilation.

C. O. Lens: The flashboards used on the crest of the intake dam and also on the crest of the storage dam, are a type which has been used extensively in Switzerland. It consists of a board hinged at the bottom, which is fastened to the crest of the dam; at the upper end of this flashboard cables are attached. These cables in turn are connected to grooved winding drums, these winding drums being a counterweight to the pressure which is back of the board. The board, if mathematically worked out, it will be seen, requires about equal inertia in any position to move one way or the other, depending on the true balance condition that may exist and so forth. So it is a movement depending on which predominates, whether it is the water pressure or the dead weight of the rolling weight. This rolling weight runs up a toothed rack, and its form is such that it requires practically the same inertia to move in whatever position it is in. These boards have been in operation in countries where they have been subjected to ice, although there may be some question whether they would be satisfactory in releasing heavy ice over the top or not. In this particular case, we considered that there would be no real objection for there would be no ice present. So there is really nothing but a moving, rolling weight against the hydrostatic pressure back of the board.

Mr. Biglow: Is there any trouble with trash coming down?

C. O. Lens: No, they have found very little trash accumulates and there is no trouble with it on the racks. Even the amount that flows on the surface is not of very great moment.

A reservoir dam is back of the intake dam, and it accumulates there, unless the floods take it over.

Mr. Biglow: I have seen a good deal of it on the Choctohachee.

C. O. Lens: No, there would not be much, because the back ridge is pretty heavily wooded and timbered and the reservoir back of the storage dam, as well as the reservoir of the intake dam, was particularly well cleared. It was not only detimbered, but practically everything was cleared off so there is very little trouble from foreign matter carried over the dam.

Geo. A. Hoadley: I have been interested in the comparison between two of the expenses mentioned in the last table. This appears to be a work in which the engineering operation is the larger element, but I have been considerably surprised in noticing that the general engineering expense is but $3.07, while the general legal expense is $1.89, considerably more than one-half of the general engineering expense. Now is there any particular explanation of that? That is, does it include anything more than the searching of titles and such legal work?

C. G. Adsit: This item of legal expense does not include any abnormal charges. It is my belief and experience that 1.7 per cent for legal expense is low rather than high. I think on work as large as this and especially water power work involving various water rights and transmission lines involving the condemning of property, that you usually find as many lawyers as you do engineers in connection with the development.

There was one question regarding reactance. We have no special reactance in the generating station of Tallulah Falls beyond that in the generators themselves. That is, no external reactance to limit the current on short circuit. The high-tension side of the transformer installation is connected in star with the neutral grounded. In case the transmission line conductors are grounded there is a resistance provided between the ground connection and the transformer neutral which is intended to limit short-circuit current. We have had only one instance, so far as we know, where the transmission lines have fallen and that was on a connected system and not on our own. The only evidence at that time that anything unusual had taken place was the indication of fluctuating load on the generators and the heating up of this ground resistance. Otherwise we would not have known that a short circuit had occurred. We did not see the necessity of external reactance in this installation unless the short circuit occurred on the low-tension conductors. We are protected against this occurrence as nearly as possible with the proper construction without the use of reactance. There has been but one short circuit on the low-tension conductors and that between conductor and ground, which was caused by rats standing on the pipe supports and reaching the conductors. What the magnitude of this short circuit was we do not know, except that it seriously burned the switch cell structure.

Harold Pender: What about lightning?

C. G. Adsit: Yes, something was said about lightning troubles. We have not had any serious lightning troubles of any nature. While we have not been entirely free of lightning disturbances the shut-down sdue to this cause have been very few and it has been uncertain as to whether these shut-downs were due to lightning or other disturbances.

R. B. Owens: Are your arresters at the receiving end only, or where are they?

C. G. Adsit: At both ends and in the center of the transmission lines.

R. B. Owens: How did you determine that was the best place for them?

C. G. Adsit: It was the convenient place rather than the best place.

R. B. Owens: You charged them every day?

C. G. Adsit: Every night when the load is light we charge the arresters at each location.

R. B. Owens: What has been your experience with the out-door type of high-tension switch?

C. G. Adsit: Well, we are changing them all now. I might say to that question that we have made a great many experiments on out-door switches in connection with this transmission line. We find that the various types of outdoor switches had no trouble in opening the energy current, but they would not open the charging current of the line.

Lars Jorgensen: The figures given seem to be reasonable and about what could be expected for the character of work done. There is possibly one exception, that of the diverting dam. For this the authors state that the cost was about $3.70 per cubic yard in place. For the mix given, the cement will cost $1.40, taking into account that only two-thirds of a yard of actual concrete is needed per unit volume of structure, the remaining one-third being rock thrown in after pouring. This leaves $2.30 per yard for rolling sand, mixing concrete, construction plant, the rock portion, etc. Some of the rock excavated from the foundation and for which the contractor was paid $1.50 per yard can possibly be used for plumstones, but much more would undoubtedly have to be quarried for the purpose, therefore the price given seems exceptionally low and the work must have been done in a very economical manner. Thirty-four per cent of " plums " in a dam is a large percentage, and it has undoubtedly required some hand placing to get this large percentage in. The fact that the dam has cracked but little is probably due to the presence of this large percentage of plumstones, and to the fairly slow progress made (1000 yards per week), and because the dam was mostly built during the winter. The slight curvature given the dam could not be expected to keep down any tendency to develop cracks which might exist.

The paper does not give any information as to the saving

effected by substituting the welded penstock pipes for riveted pipes towards the lower end. It would be very interesting to know something about this, both as to the money saving effected and the head gained. This head has undoubtedly been measured by this time.

The writer had an opportunity to watch a welded 30-inch diameter pipe go in this summer on a hydroelectric installation utilizing about 1280 ft. head. This pipe was made in the United States in a manner similar to that in use in Germany, and was in every respect an excellent piece of work. From tests made to determine the strength of the weld it was learned that the joint efficiency was between 96 per cent and slightly above 100 per cent. That it could be above 100 per cent is probably due to the fact that the material is worked more at the lap when being welded. The maximum plate thickness in the welded portion of the pipe was $\frac{1}{4}$ inch. Below this thickness riveted pipe was used, but this was a very small portion of the total. The saving effected in comparison with a riveted pipe was quite material.

Discussion on "The Magnetic Properties of Some Iron Alloys Melted in Vacuo" (Yensen), St. Louis, Mo., October 20, 1915. (See Proceedings for October, 1915.)

(Subject to final revision for the Transactions.)

Thomas Spooner: The Burrows permeability apparatus we have used in our commercial testing for some years, and found it very satisfactory, especially when used in connection with the Grassot flux-meter. The apparatus has given us very accurate checks for the Bureau of Standards certified rods. We, of course, have not had occasion to test samples of permeability of 60,000 to 70,000, but for commercial material we feel sure that the apparatus is extremely accurate.

In regard to the question of bending, we discovered the same fact Mr. Yensen did, some time ago, when we first put our Burrows apparatus in commission. We had two sets of yokes which were mechanically exactly alike, and still, to make sure, we tried testing two rods in each set of yokes, to make certain that the two pieces of apparatus were identical, and we found that we were not able to check within several per cent. After considerable work we discovered that it was undoubtedly due to a little difference in the yokes which produced strain in the rods.

Only the other day I got a pretty good example of the effect of bending. I received from the annealing room a sample of sheet material which was bent. It was rather heavy gage material, and of course I knew it would not test correctly, but as a matter of interest I put it in the yokes and got a permeability test at an induction of 10 kilogausses. The permeability was approximately fifty per cent of what it should have been, showing the effect of bending.

In regard to the vacuum treatment, we have not made any alloys melted in vacuo, but we have done a little work on vacuum annealing, and we have not been able to find that the vacuum treatment was of any particular benefit. I would ask Mr. Yensen if he attributes the high values of permeability which he has obtained in any degree to the large size of crystals which his micrographs show.

W. J. Wooldridge: The first thing I note about the results is that the samples are all in the shape of rods, and while cast or forged material is of considerable interest, sheet material is of greater importance. Several years ago we made some tests on rods cut from open hearth steel and silicon steel from various parts of the ingot or bloom, rods from the sheet bar and samples from sheets, the object being to ascertain the changes due to different degrees of working.

The principal results were as follows:

	O. H. Steel	*Si* Steel	*Si* Steel
Ingot	0.0147	0.0089	0.0099
Sheet bar	0.0233	0.0119	0.0119
Sheet	0.0239	0.0157	0.0163

hysteresis, watts per pound per cycle at B-10,000. Tests were made by the isthmus method.

From these figures it will be noted that results are changed vastly by the mechanical working necessary to produce sheets and which changes and stresses the structure of the material. Further, and this has been borne out by other tests, it has appeared that material which is primarily of exceptionally good characteristics magnetically, is most susceptible to change. It would, therefore, be of very great interest to know how these new materials will behave after being rolled into sheets, provided it is mechanically possible to do so.

No mention is made of eddy current losses which must be of considerable magnitude in the rods and may be such as to mask the real hysteresis values. The eddy current loss cannot be considered as inversely proportional to the specific resistance, but is usually of much greater range, due, doubtless, to the different internal structures. This may be still more exaggerated in unlaminated samples. Materials having the same specific resistance vary greatly in respect to eddy current losses. Hysteresis reduction alone is not indicative of real improvement as material has been produced in which a very considerable reduction in hysteresis has been obtained, but in which the eddy loss has increased to such an extent that the net result was an actual increase in total iron losses.

We have also noted in some cases an exalted or temporary but unstable condition especially with reference to permeability. In certain electrolytic iron and also in material annealed and cooled in a magnetic field the first test showed very high maximum permeability which on later tests could not again be found. This apparently is a condition akin to aging of hysteresis which was put upon the shelf with the advent of the silicon alloys. This exalted condition is one very difficult of explanation, but is one of certain occurrence and one which is worthy of careful study, but which teaches us the need of caution in dealing with new or specially treated materials unless they have been carefully retested after a lapse of time or after such handling or temperature exposure as the material would get in practise.

Of the value of vacuum fusion or heat treatment there seems no doubt, but in the practical application to mill manufacturing conditions there are great difficulties. New practises would have to be worked out, which would, doubtless add very greatly to the cost of producing the sheets. Uniformity of the product to a very close degree would be absolutely essential when working at high densities, but the extraordinarily high permeability shown seems to be very delicately poised, as shown by the samples 3 *Si* 36 and 3 *Si* 37.

Nevertheless the fact remains that, assuming results given us to be correct, it will doubtless be a great incentive to further investigation and to the study of ways and means to overcome

what look like great difficulties in order to obtain and benefit by the great improvements.

John D. Ball: From the results obtained by Mr. Yensen, and from other tests which I have been privileged to review, I feel that it is definitely shown that the vacuum fusing treatment gives to certain magnetic materials an increase for the value of maximum permeability, which is usually accompanied by the lowering of the hysteresis losses. It is strongly indicated that for materials so treated, the induction at which maximum permeability values occur, are also higher than for our regularly treated product. All three of these characteristics are highly desirable and important.

The values given in this paper are very unusual and much more startling than have previously been obtained. I have made a somewhat extended, though of necessity hurried, analysis of these results and have been forced to conclude that some inconsistencies are present, as the analysis shows abnormally high and varying values of the ratio of hysteresis losses at $B = 15{,}000$ and $B = 10{,}000$, and further analyses show that the indicated values of saturation as derived from these published results are from two to six times the maximum values given for any material. This shows that Mr. Yensen's alloys are either more remarkable than appears at a casual study of the paper, or that the values of maximum permeability, as given, are exaggerated.

Analyses of Hysteresis Results. The normal increase of hysteresis loss with increased induction is given by the well known law $h = \eta B^{1.6}$. In the case of some materials it has been noted that at high inductions the loss apparently increases faster than would be given by the above equation. This may be accounted for by the fact that the steel tested is not homogeneous, but contains impurities such as scale etc., which in themselves follow the law but have different constants. The more scale or hetrogeneous the material, the greater deviation may be expected. Tests on many samples of 2½ per cent silicon and 3½ per cent silicon steel as commercially used, show the losses at $B = 15{,}000$ to be 30 per cent higher than would be given by the loss at $B = 10{,}000$ and strict application of the law by assuming the material to be homogeneous. For scale-free material this ratio is less. For vacuum-fused steel we would expect less oxidization, greater purity and therefore a ratio of loss coefficient, at $B = 15{,}000$ divided by $B = 10{,}000$ somewhat less than 1.3 but of course greater than 1.0, the corresponding ratio of losses themselves being 4.5 to the value of $\left(\frac{15{,}000}{10{,}000}\right)^{1.6} = 1.91$. Taking hysteresis data from the paper and calculating the values of η and the ratios, gives us results on rods annealed at 1100 deg. cent. as shown in Table I. Here we find ratios from 1.07 to 1.90, and anything you like between,

independent of the silicon content. For the two samples showing the high permeability we find ratios of 1.68 and 1.90; that is, in the latter case the loss at $B = 15{,}000$ is something like four times the loss at $B = 10{,}000$, or about twice that given by the Steinmetz law. This indicates either a very low loss

TABLE I.

RODS ANNEALED AT 1100 DEG. CENT.

Sample	Si.	Perm. Max.	Perm. At B = 10,000	Hysteresis B = 10,000	Hysteresis B = 15,000	Value for η B = 10,000	Value for η B = 15,000	Ratio
3-54	0.001	22,800	21,300	665	1860	0.265×10^{-3}	0.387×10^{-3}	1.46
3-55	0.001	25,800	25,600	707	1451	0.282	0.302	1.07
3Si16	0.01	29,000	28,670	707	1604	0.282	0.334	1.18
3Si21	0.048	27,000	27,000	700	1660	0.279	0.346	1.24
3Si15	0.064	36,800	36,300	502.5	1336	0.200	0.278	1.39
3Si05	0.068	44,200	43,500	407	1214.5	0.162	0.253	1.56
3Si22	0.091	45,250	43,500	394	929	0.157	0.193	1.23
3Si06	0.148	66,500	41,700	286	916	0.114	0.191	1.68
3Si23	0.205	30,200	29,500	649	1526	0.258	0.318	1.23
3Si07	0.242	36,500	33,000	436	1346	0.174	0.280	1.61
3Si08	0.309	44,500	43,500	445	1412	0.177	0.294	1.66
3Si09	0.400	22,500	22,000	725	1820	0.289	0.378	1.31
3Si10	0.472	31,150	25,000	535	1358	0.213	0.282	1.32
3Si11	0.563	25,000	25,000	601.5	1624	0.239	0.338	1.41
3Si12	0.673	28,000	24,500	468	1636	0.186	0.340	1.83
3Si13	0.698	20,350	19,600	780	2220	0.311	0.461	1.48
3Si14	0.822	30,800	30,300	542	1765	0.216	0.368	1.71
3Si31	1.71	30,150	24,700	440	1292	0.175	0.269	1.54
3Si18	1.741	33,000	26,300	416	1112	0.166	0.232	1.40
3Si27	2.73	46,800	46,000	404	1260	0.161	0.262	1.63
3Si25	3.40	63,300	46,500	280	1025	0.112	0.213	1.90
3Si36	3.55	36,000	29,500	419	1157	0.167	0.240	1.44
3Si37	4.39	25,700	15,400	591	1819	0.235	0.378	1.61
3Si28	4.44	30,200	15,900	405	1176	0.161	0.244	1.52
3Si29	4.92	12,200	7,040	780	2620	0.311	0.545	1.75

material, which saturates at an induction between $B = 10\ 000$ and $B = 15{,}000$, after which the flux goes into a material having a high hysteresis loss, or there is some inaccuracy of test. The losses themselves are very low. For regular $3\frac{1}{2}$ per cent silicon steel a fair average figure of η at $B = 10{,}000$ would be 0.7×10^{-3}. At $B = 15{,}000$ we would expect 30 per cent higher. The results given in this paper show only about one-third

of the hysteresis loss of ordinary transformer steel. The calculations of rods annealed at 900 deg. cent. are given in Table II. This anneal gives much lower values of maximum permeability also ratios of η which are comparable with our experience with present materials.

It would be of interest to note results of tests on ordinary materials made by using Mr. Yensen's apparatus. As none are given in the present paper, I ask the liberty to quote some results recently published by Mr. Yensen in the *General Electric Review*.* Table III gives some of these tabulated results together with

TABLE II.
RODS ANNEALED AT 900 DEG. CENT.

Sample	Si.	Perm.		Hysteresis		Values for η		Ratio
		Max.	$B =$ 10,000	$B =$ 10,000	$B =$ 15,000	$B =$ 10,000	$B =$ 15,000	
3-54	0.001	23,100	21,800	764	1610	0.302×10^{-3}	0.335×10^{-3}	1.11
3-55	0.001	22,500	21,300	875	1790	0.348	0.372	1.07
3Si16	0.01	25,000	25,000	795	1770	0.317	0.368	1.16
3Si15	0.064	22,800	21,700	782	1738	0.311	0.362	1.17
3Si05	0.068	37,500	36,300	405	1210.5	0.161	0.252	1.56
3Si06	0.148	47,000	42,500	396.3	965	0.158	0.201	1.27
3Si17	0.230	30,000	26,300	496	1311	0.198	0.273	1.38
3Si10	0.472	14,000	12,700	960	1863	0.382	0.388	1.02
3Si14	0.822	13,500	13,300	1215	2432	0.484	0.506	1.33
3Si31	1.71	18,000	15,900	800	1541	0.318	0.321	1.01
3Si18	1.741	14,300	14,100	935	2162	0.372	0.450	1.21
3Si27	2.73	16,800	13,300	821	1779	0.327	0.370	1.13
3Si25	3.40	20,000	15,900	560	1390	0.223	0.289	1.30
3Si36	3.55	14,000	8,850	802.5	1812	0.319	0.377	1.18
3Si37	4.39	12,750	7,500	846	1956	0.337	0.406	1.21
3Si28	4.44	16,100	10,100	623	1575	0.248	0.328	1.22
3Si29	4.92	9,100	5,330	776	2006	0.309	0.417	1.35

my calculations of η. Here we find the ratio of hysteresis losses for commercial grades of steel to be less than unity, or in other words, flux passes through hard material before going through paths of less reluctance. These ratios quite disagree with our present conceptions and are entirely contrary to our wide experience with these materials.

By adding results of samples having the highest permeability as given in the paper and plotting maximum permeability

*"The Iron-Cobalt Alloy Fe_2CO and its Magnetic Properties." T. D. Yensen. *G. E. Rev.* Vol. XVIII, 1915. pp. 881-887.

against η we find a curve showing low permeability for high hysteresis, which has often been observed. However, by plotting maximum permeability against the ratio of η's we see the greater maximum permeability the more unusual this ratio. These curves are shown in Fig. 1.

Analyses of Permeability Results. One of our strongest methods of attack for certain problems is by use of the reluctivity curve which is the reciprocal of the permeability plotted against H. From maximum permeability this approximates a straight line as has been pointed out upon several occasions.*

A typical reluctivity curve is shown in Fig. 2.

The reluctivity, ρ, is given by the equation $\rho = \alpha + \sigma H$

TABLE III.*

Specimen	Max. permeability	Hysteresis B = 10,000	Hysteresis B = 15,000	η B = 10,000	η B = 15,000	η Ratio
Pure Iron (Vac.)...	22,800	820	1700	0.326×10^{-3}	0.354×10^{-3}	1.09
Fe_2 Co. (Vac.).....	13,200	1460	3200	0.582	0.666	1.14
Com. Grades.						
Trans. Steel.......	3,850	3320	5910	1.32	1.23	0.93
4% Si Steel........	3,400	2260	3030	0.900	0.631	0.70
Swedish Iron......	4,850	2490	4530	0.992	0.944	0.95
Pure Iron (Vac.)...	24,300	686	1655	0.273	0.345	1.26
Fe_2 Co. (Vac.).....	8,800	2230	4400	0.888	0.916	1.03
A. I. E. E. Paper.						
0 015% Si (Vac.)...	66,500	286	916	0.114	0.191	1.67
3.40% Si (Vac)....	63,300	280	1025	0.112	0.213	1.90

*From *General Electric Review*, August 1915, p. 884.

wherein α is a constant representing the distance from the X axis to the intercept of $\rho - H$ curve if continued along the straight line, and σ a constant representing the slope of the line. The constant σ has also been named the coefficient of magnetic saturation because its reciprocal gives the value of absolute saturation of metallic induction.

In Fig. 2 we have two straight lines, the break is at about $H = 80$. There may be more than one change in the slope

*"Magnetic Reluctance." A. E. Kennelly, Trans. A.I.E.E., Vol. VIII, 1891, pp. 485-517.

"On the Law of Hysteresis." C. P. Steinmetz, Trans. A. I. E. E., Vol. IX-1892. pp. 625 et seq.

"Reluctivity of Silicon Steel", J. D. Ball, *G. E. Rev.*, Vol., XVI, 1913. pp. 750-754.

of a complete curve, depending upon the heterogeneity of the material. Examining the curve we note that from maximum permeability to about $H = 80$ most of the flux enters a part of the material having an ultimate saturation of $B = 17{,}000$, then as this saturates the additional flux passes through material whose ultimate saturation is in the neighborhoo d o $B = 20{,}000$. Tests made at very high magnetizations by use

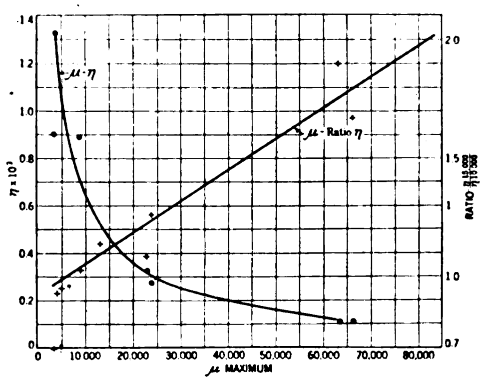


FIG. 1—μ-η AND μ-RATIO η CURVES FROM RESULTS OF YENSEN IN *G. E. Review*

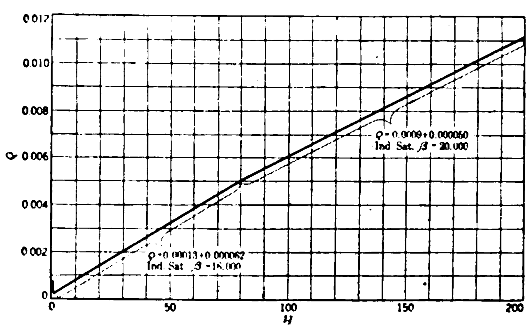


FIG. 2—H-ρ CURVE FOR STEEL

of the isthmus method,* check ultimate saturation values as found by $\frac{1}{\sigma}$ of the ρ curve taken at moderate field strengths. To find the slope of the ρ - H curve, it is of course best to have

*See " Electrical Properties of Iron and its Alloys, in Intense Fields." Sir Robt. Hadfield and Prof. B. Hopkinson, Journ. I. E. E., Vol. LVI, 1911, pp. 235-306, etc.

several points, but as in Mr. Yensen's paper we have permeability results at only two points. I have analyzed the reluctivity curves and found ultimate saturation values from the values given at maximum permeability and $B = 10{,}000$. This method is not ideal but should give good average results. For comparison I have taken some regular material and analyzed

TABLE IV.

ANALYSES OF COMMERCIAL STEELS.

	At Maximum Permeability.				At $B = 10{,}000$		
Sample	μ	B	H	ρ	μ	H	ρ
1	5880	4000	0.68	1.70×10^{-4}	3830	2.61	2.61×10^{-4}
2	6020	5000	0.83	1.66	3760	2.66	2.66
3	5810	5000	0.86	1.72	3660	2.73	2.73
4	5100	5000	0.98	1.96	2950	3.39	3.39
5	5440	5000	0.92	1.84	3270	3.06	3.06
56	5000	5000	1.00	2.00	2600	3.85	3.85
68	4720	5000	1.06	2.12	2790	3.58	3.58
1961	5040	6000	1.19	1.98	3450	2.90	2.90
Av. of 22	6000	6000	1.00	1.67	3850	2.60	2.60
6679	5380	5000	0.93	1.86	3200	3.12	3.12
2670	5170	6000	1.16	1.93	3560	2.81	2.81
1078	5610	6000	1.06	1.78	3700	2.70	2.70
1112	5230	8000	1.53	1.91	4200	2.38	2.38
6724	6020	5000	0.83	1.66	3950	2.53	2.53
1092	5550	6000	1.08	1.80	4020	2.49	2.49
1062	5040	6000	1.19	1.98	3510	2.85	2.85
6681	5260	5000	0.95	1.90	3390	2.95	2.95
2776	4650	6000	1.29	2.15	3530	2.83	2.83
1962	3140	6000	1.19	3.19	2325	4.30	4.30
Sank*	2650	5300	2.0	3.78	1820	5.5	5.5
Wtg†	8340	6200	0.74	1.20	3920	2.58	2.58
Lond‡	1670	8350	5.0	5.99	1470	6.8	6.8
Flem §	3330	6670	2.0	3.0	2380	4.2	4.2

*Sankey's transformer steel, Morris and Langford, *Lond. Elect.* Vol. 67, page 776.
†Test on steel taken from commercial transformer.
‡Silicon steel, *Lond. Elect.* Vol. 66, page 539.
§Sankey's iron, J. A. Fleming, Proc. Royal Soc. Vol. 60, page 1896.

it by using these two points. Table IV shows the permeability B, H and ρ for these two points. The first group of nine samples is for high silicon steel containing from 3.5 to 4 per cent silicon. The first eight lines are individual samples and the "av." is an average of 22 samples taken from material carefully tested during the last year or so. The next group

of eight samples is of medium silicon steel containing about $2\frac{1}{2}$ per cent *Si*. The next two samples are for carbon iron. The last four samples are from published results. If time had permitted I should have included more of these but have taken the first four which happened to be at hand.

The analyses to find σ, α and ultimate saturation are given in Table V. Doubtless the ρ curve bends beyond $B = 10{,}000$ and approaches a saturation value of about $B = 22{,}000$.

TABLE V.

ANALYSES OF COMMERCIAL STEELS.

Sample	$\Delta\rho$	ΔH	$\frac{\Delta\rho}{\Delta H} = \sigma$	σH_{10}	$\rho_{10} - \sigma H_{10} = \alpha$	Ind. Sat.
1	0.91×10^{-4}	1.93	0.471×10^{-4}	1.23×10^{-4}	1.38×10^{-4}	21,240
2	1.00	1.83	0.546	1.54	1.12	18,310
3	1.01	1.87	0.540	1.48	1.25	18,520
4	1.43	2.41	0.593	2.01	1.38	16,850
5	1.22	2.14	0.57	1.75	1.31	17,550
56	1.85	2.85	0.649	2.50	1.35	15,400
68	1.46	2.52	0.579	2.07	1.51	17,270
1961	0.92	1.71	0.538	1.56	1.34	18,580
Av. of 22	0.93	1.60	0.581	1.51	1.10	17,200
6679	1.26	2.19	0.575	1.79	1.33	17,400
2670	0.88	1.65	0.553	1.50	1.31	18,750
1078	0.92	1 63	0.564	1.52	1.18	17,730
1112	0.47	0.85	0.553	1.32	1.06	18,075
6724	0.87	1.70	0.512	1.30	1.23	19,530
1092	0.69	1.41	0.489	1.22	1.27	20,440
1062	0.87	1.66	0.524	1.49	1.36	19,080
6681	1.05	2.00	0.525	1.55	1.40	19,050
2776	0.68	1.54	0.442	1.25	1.58	22,600
1962	1.11	2.39	0.465	2.00	2.30	21,500
Sank	1.72	3.5	0.492	2.71	2.79	20,350
Wtg.	1.35	1.84	0.734	1.89	0.66	13,600
Lond.	0.81	1.8	0.45	3.06	3.74	22,200
Flem.	1.2	2.2	0.545	2.29	1.91	18,300

The method of making these analyses is comparatively simple. The differences of the reluctivity values for two points divided by the difference of the value of *H*, gives us σ, the slope of the line. The indicated saturation is the reciprocal of σ. The slope, σ, times *H* at any point subtracted from ρ at that point gives us the intercept α.

Table VI gives μ, *H* and ρ results for Mr. Yensen's rods annealed at 1100 deg. cent. Table VII gives the analyses. Here we find according to these tests, for a short time at least,

flux is going through material having an ultimate saturation of from 15,800 (which is consistent), to an ultimate saturation value of $B = 140{,}000$, which is over six times any value ever before obtained. The amount of variations between samples is also unusual. The values of α also show unusual variations, but this latter may be correct.

TABLE VI.

RODS ANNEALED AT 1100 DEG CENT.

Sample	At Maximum Permeability.				At $B = 10{,}000$		
	μ	B	H	ρ	μ	H	ρ
3-54	22,800	8,000	0.351	0.439×10^{-4}	21,300	0.469	0.469×10^{-4}
3-55	25,800	9,000	0.349	0.388	25,600	0.391	0.391
3Si16	29,000	9,000	0.310	0.345	28,670	0.349	0.349
3Si21	27,000	10,000	0.370	0.370	27,000	0.370	0.37
3Si15	36,800	9,000	0.244	0.272	36,300	0.275	0.275
3Si05	44,200	9,000	0.204	0.226	43,500	0.230	0.23
3Si22	45,250	9,000	0.199	0.221	43,500	0.230	0.23
3Si06	66,500	6,500	0.0978	0.150	41,700	0.240	0.24
3Si23	30,200	9,000	0.298	0.331	29,500	0.339	0.339
3Si07	36,500	7,500	0 205	0.274	33,000	0.303	0.303
3Si08	44,500	9,000	0.202	0.225	43,500	0.230	0.230
3Si09	22,500	9,000	0.400	0.445	22,000	0.455	0.455
3Si10	31,150	6,200	0.199	0.321	25,000	0.400	0.40
3Si11	25,000	9,000	0.360	0.400	25,000	0.400	0.40
3Si12	28,000	7,000	0.250	0.357	24,500	0.408	0.408
3Si13	20,350	8,000	0.393	0.491	19,600	0.510	0.510
3Si14	30,800	9,500	0.308	0.325	30,300	0.330	0.33
3Si31	30,150	6,500	0.215	0.332	24,700	0.405	0.405
3Si18	33,000	7,000	0.212	0.303	26,300	0.380	0.380
3Si27	46,800	9,500	0.203	0.214	46,000	0.217	0.217
3Si25	63,300	6,500	0.1026	0.158	46,500	0.215	0.215
3Si36	36,000	7,500	0.208	0.278	29,500	0.339	0.339
3Si37	25,700	6,000	0.233	0.389	15,400	0.649	0.649
3Si28	30,200	3,000	0.099	0.331	15,900	0.629	0.629
3Si29	12,200	5,000	0.410	0.820	7,040	1.420	1.42

Tables VIII and IX give similar analyses for rods annealed at 900 deg. cent. Here again we have remarkable saturation values, etc.

These analyses would indicate that there may be something wrong somewhere and undoubtedly the trouble is in the test. The Burrows apparatus which was used, is the standard method recommended by the U. S. Bureau of Standards and also the

standard of the American Society of Testing Materials. Its accuracy for permeability of ordinary magnitude has been accepted, but at these high values I am inclined to question its reliability. There is a considerable amount of m.m.f. and energy supplied to the system in the so-called J or compensating coils of which no account is taken in the test. When the permeability is very large the energy supplied by these coils may be sufficient to affect results. This would mean that any error would be in the direction which would show high permeability and too low hysteresis loss.

TABLE VII.

RODS ANNEALED AT 1100 DEG. CENT.

Sample	$\Delta \rho$	ΔH	$\frac{\Delta \rho}{\Delta H} = \sigma$	σH_{10}	$\rho_{10} - \sigma H_{10} = \alpha$	Ind. Sat.
3-54	0.030×10^{-4}	0.118	0.264×10^{-4}	0.119×10^{-4}	0.350×10^{-4}	39,400
3-55	0.003	0.042	0.0714	0.0279	0.363	140,000
3Si16	0.009	0.039	0.0816	0.0285	0.320	122,500
3Si15	0.003	0.031	0.0967	0.0266	0.248	103,300
0Si05	0.004	0.026	0.154	0.0364	0.194	65,000
3Si22	0.009	0.031	0.290	0.0668	0.163	34,500
3Si06	0.09	0.142	0.634	0.152	0.088	15,800
3Si23	0.008	0.041	0.19	0.0644	0.275	52,600
3Si07	0.029	0.098	0.296	0.0897	0.213	33,800
3Si08	0.005	0.028	0.179	0.0411	0.189	56,000
3Si09	0.010	0.055	0.182	0.0828	0.372	55,000
3Si10	0.079	0.201	0.393	0.157	0.243	25,400
3Si12	0.051	0.158	0.323	0.132	0.276	31,000
3Si13	0.019	0.117	0.162	0.083	0.427	61,600
3Si14	0.005	0.022	0.227	0.0728	0.257	44,000
3Si31	0.073	0.190	0.384	0.155	0.250	26,000
3Si18	0.077	0.168	0.458	0.174	0.206	21,800
3Si27	0.003	0.014	0.214	0.0465	0.171	46,700
3Si25	0.057	0.112	0.509	0.109	0.106	19,700
3Si36	0.061	0.131	0.466	0.158	0.181	21,500
3Si37	0.26	0.416	0.624	0.405	0.244	16,000
3Si28	0.298	0.530	0.563	0.354	0.275	17,800
3Si29	0.6	1.010	0.594	0.844	0.576	16,800

Of course, we must appreciate the fact that this analysis for ultimate saturation is not entirely dependable. If more points were available, or if the points given were further apart,

TABLE VIII.

RODS ANNEALED AT 900 DEG. CENT.

Sample	At Maximum Permeability.				At B = 10,000.		
	μ	B	H	ρ	μ	H	ρ
3-54	23,100	8,500	0.368	0.433×10^{-4}	21,800	0.459	0.459×10^{-4}
3-55	22,500	11,000	0.489	0.445	21,300	0.469	0.469
3Si16	25,000	10,000	0.400	0.400	25,000	0.400	0.400
3Si15	22,800	10,000	0.439	0.439	21,700(?	0.461	0.461
3Si05	37,500	9,000	0.240	0.267	36,300	0.275	0.275
3Si06	47,000	8,000	0.170	0.213	42,500	0.235	0.235
3Si17	30,000	6,000	0.200	0.333	26,300	0.380	0.380
3Si10	14,000	7,000	0.500	0.712	12,700	0.788	0.788
3Si14	13,500	9,000	0.667	0.740	13,300	0.752	0.752
3Si31	18,000	7,000	0.389	0.556	15,900	0.629	0.629
3Si18	14,300	8,000	0.559	0.700	14,100	0.709	0.709
3Si27	16,800	6,000	0.357	0.595	13,300	0.752	0.752
3Si25	20,000	6,000	0.333	0.500	15,900	0.629	0.629
3Si36	14,000	4,500	0.321	0.714	8,850	1.130	1.13
3Si37	12,750	4,500	0.353	0.784	7,500	1.330	1.33
3Si28	16,100	4,800	0.298	0.621	10,100	0.991	0.991
3Si29	9,100	4,500	0.495	1.098	5,330	1.875	1.875

TABLE IX.

RODS ANNEALED AT 900 DEG. CENT.

Sample	$\Delta \rho$	ΔH	$\frac{\Delta \rho}{\Delta H} = \sigma$	σH_{10}	$\rho_{10} - \sigma H_{10} = \alpha$	Ind. Sat
3-54	0.026×10^{-4}	0.091	0.286×10^{-4}	0.131×10^{-4}	0.328×10^{-4}	35,000
3-55						
3Si16						
3Si15						
3Si05	0.008	0.035	0.229	0.0629	0.212	43,700
3Si06	0.022	0.065	0.339	0.0796	0.155	29,500
3Si17	0.047	0.180	0.261	0.0992	0.281	38,300
3Si10	0.076	0.288	0.264	0.208	0.580	37,900
3Si14	0.012	0.085	0.141	0.102	0.650	70,800
3Si31	0.073	0.240	0.304	0.191	0.438	32,900
3Si18	0.009	0.150	0.600	0.04254	0.666	167,000
3Si27	0.157	0.395	0.397	0.288	0.464	25,100
3Si25	0.129	0.296	0.436	0.274	0.355	22,900
3Si36	0.416	0.809	0.514	0.581	0.549	19,500
3Si37	0.546	0.977	0.559	0.744	0.586	17,900
3Si28	0.370	0.693	0.534	0.529	0.462	18,700
3Si29	0.777	1.380	0.563	1.055	0.820	17,800

we would have more reliable and in this case doubtless more consistent results. At the point of maximum permeability, or minimum reluctivity the slope of the $\rho - H$ curve is 0 and the indicated saturation is ∞. As the second point taken approaches the maximum permeability we are likely to lead into errors. In many of Mr. Yensen's results, the induction at which maximum permeability occurs, is closer to $B = 10{,}000$ than would entirely warrant the point at $B = 10{,}000$ as a second point to determine the line if others were available. In order to examine this feature I plotted B at maximum μ against indicated saturation. Fig. 3 shows the points and we see a tendency to higher indicated saturation values as the points are closer together. However, at $B = 8000$ we get saturation of 167,000 and at $B = 9500$ nothing over 47,000.

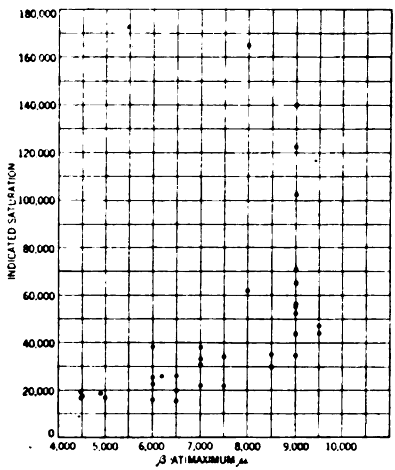


FIG. 3—INDICATED SATURATION CURVE

At $B = 9000$ we get from 34,000 to 140,000 and our values for regular materials are consistent. Therefore we can see the analysis is reasonably correct at the points taken. I am giving these figures for what they are worth. In all probability the correct view to assume is that the permeability values are actually neither as inconsistent as my figures show nor as good as Mr. Yensen obtains from his test.

It would be interesting to see if these analyses show any dependence between maximum μ and indicated saturation. We know for ordinary materials there is none. For steel alloys we have a nearly constant value of ultimate saturation. We may approach this value quickly (for instance by adding titanium) or very slowly as in case of some tungsten-steel alloys. The maximum permeability varies accordingly. In the present case the plot of indicated saturation and maximum

permeability as given on Fig. 4 shows no interdependence, which is as would be expected.

We have sometimes found materials which were apparently exceptionally good, to age very rapidly, and I should like to ask Mr. Yensen if he has made tests of this character on this material.

It is a well known fact that rods show better magnetic properties than sheet steel. I would therefore like to ask if there are any results on this material in sheet form as it is mostly used in the industries.

I do not wish to fail in pointing out that these results are very good and that the paper is very valuable. The points which I have given are not to show that the investigation is not excellent, but that the magnitudes of the magnetic improvement as given by the test results are too high.

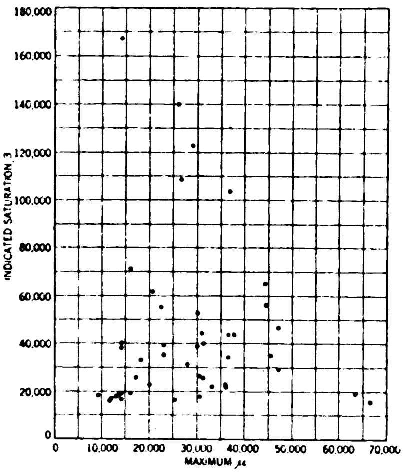


FIG. 4—INDICATED SATURATION CURVE

In checking hysteresis by the Burrows method, you drop from one compensating point to another, and you go to your maximum B and then you go down on the loop. I ask Mr. Yensen, in compensating, when he goes from an induction of 10,000 to say, 8000, if he drops from a predetermined position on the normal induction curve or whether he compensates for the difference in the change of flux. It necessarily cannot follow the same path, for if even the test sample and the auxiliary sample may, yet the yokes, having different permeability, cannot. I ask if any one knows of errors of that kind. Mr. Yensen loaned to my colleague, Mr. Ruder, one of these samples, and one was sent to the Standardization Laboratory where Mr. Robinson had it tested. We tested it and made a change by having the compensated coils next

to the sample. We tested it in that manner. In this case the error due to the compensated coils was less. The tests indicated that the results Mr. Yensen obtained and those we obtained were practically identical, one is 74,000 and the other is 68,000, and when you talk of permeabilities of that magnitude we appreciate that a little matter of 2000 or 3000 does not amount to anything. That does not prove the material is that good, but proves it on the order of magnitudes indicated by these tests.

Thomas Spooner: Mr. Burrows, according to his original article, suggests that the compensating winding be placed approximately half way from the center to the yoke. Judging from Mr. Yensen's diagram, he has his compensating winding out pretty near to the yoke. It seems to me that placing the compensating winding so far out would tend to increase the compensating current in certain coils and consequently would decrease the main magnetizing current. I do not know whether that accounts for the high permeabilities obtained by Mr. Yensen or not. I offer it as a suggestion.

Morgan Brooks: It is my understanding that the Steinmetz law which calls for a coefficient of 4.6 is an empirical formula derived from specimens of iron examined at the time the formula was developed and for frequencies within the range of commercial practise. I think it is quite possible that Steinmetz's formula should not be held to apply to any of this material of Mr. Yensen's, which is far outside of any commercial iron which was available at the time that Steinmetz developed his formula.

M. G. Lloyd: In looking over this paper, a doubt arose in my mind as to the particular figures found. I do not think, however, that is a very important point, as there seems to be no doubt that the material has characteristics at least in the direction of the results found, whether the particular numerical values are accurate or not. That is the principal matter of interest in connection with these alloys. I felt that too much dependence was naturally put upon the exact numerical values, and I must say that Mr. Ball's analysis has confirmed that in my mind to some extent, in spite of what Prof. Brooks has said. I think it should be remembered in this connection that the Burrows method of testing, which has been used here, is most suitable to material of low permeability and least suited to material of exceptionally high permeability, such as is involved in these measurements. The errors would naturally be larger in the cases here under consideration. It must be remembered that the computed errors which have been mentioned by Mr. Yensen apply to a condition in which certain assumptions are required, and there is no assurance whatever that these assumptions are fulfilled in the particular cases. If they are not fulfilled the computed correction for errors of course does not hold. I doubt very much whether the assump-

tions made for determining that correction are actually fulfilled, and they would probably be least completely fulfilled in material such as is considered in the paper, that is, material which departs so very widely from the material used in the yoke, for instance. I consequently feel that too much dependence should not be put upon the numerical values obtained.

In regard to the industrial application of the vacuum in treating the material, it seems to me that this vacuum treatment is especially necessary when treating the very pure electrolytic iron, and that the importance of the vacuum treatment would not be nearly so great in ordinary commercial material. Such material already has impurities in it, and would not be affected in the same way, so that the application of vacuum would not be of industrial importance, unless the electrolytic iron were also to be used industrially.

While the percentage of silicon seems to have a considerable effect upon the magnetic induction and permeability found in particular values of the magnetizing field, it seems that with respect to hysteresis there is not very much dependence on the amount of silicon present in the alloy; in other words, it is the treatment of the material rather than the silicon content that has the greatest effect on hysteresis. That means, of course, from the industrial standpoint, that percentage will be selected that is most easily handled mechanically, and most easily manufactured.

In comparing these silicon steels with the commercial material, Mr. Yensen found they were about eight times as good, as regards hysteresis at a flux density of 10,000 gausses. It seems to me that is not comparing it with the best commercial material. I referred back to some figures I obtained five or six years ago, and instead of being eight times as good, I found it would only be five times as good as some of the commercial material I tested at that time. I have not made any recent tests to find out how much the material has been improved, as used commercially since that time, but certainly it ought not to be any worse than it was then, so that the proportion should hardly be taken to be as great as indicated.

L. T. Robinson: As to whether the values given are numerically correct or not is not very important. We are certainly very definitely assured that these values are much higher than anything we have previously had announced.

There certainly is no question but that the values you would obtain with these compensating coils are lower than the real values, and under such conditions, that is, without compensation at all for the yoke, we got the value of 29,000. This shows beyond question that the real value is somewhere between 29,000 and 68,000.

With reference to the Burrows method, it is not out of the way to express a doubt as to what the method may do under certain very abnormal conditions which did not exist at the

time when it was developed and which undoubtedly could not be taken into account at the time the original work was done.

In regard to the ratio of 10,000 to 15,000 in hysteresis values, something might be said also, that is, there may be characteristics in the material that do not lend it to quite the same analysis you would give to the ordinary sample.

The most interesting point to me is the one covered by Mr Wooldridge, and that is the question of what becomes of material like this when it is rolled into sheet. The fact has already been noted and referred to that you can get much higher results in the rod and in the ingot than you can after it has been put into sheet, which is the form in which you are most interested in the material, and I hope that Prof. Yensen can in some way cover that point. Depending on the results obtained by such tests, will come the usefulness or non-usefulness of the material in practical work. The eddy losses in the materials, as not being a direct function of the resistivity, I have referred to many times before. I would like to see some adequate expanation offered of why, in materials which have the same thickness, the same characteristics, and may be in an apparatus of the same design, etc., there is a great discrepancy between the eddy losses and the resistivity. When we have such great discrepancies right along a line where we feel we have correct formulas and are practically familiar with the results, and when it does not check up better than 2 to 1, and we know of no adequate explanation we can offer, I think we are in no position to be very critical on results obtained on absolutely new material.

N. W. Storer: I hope that Mr. Yensen's work will result in far-reaching changes in our apparatus—not that we are anxious to change it—but if we can make such improvements as are foreshadowed by these tests, it will pay us very very richly to do it. The great question is whether it will be commercial, and while, of course, we cannot hope now to reach such high permeabilities as he has spoken of, I would be satisfied to get double the permeability of the present steel especially if it can be obtained at high densities. It would make a very substantial improvement and great reduction in the weight of much of our apparatus. We are looking for just such things. If we could only find some one who will increase the conductivity of copper in the same ratio, think where we would land. Everything would be revolutionized. The place that interests me most in the permeability curve is along the higher inductions and I would like to inquire, particularly, as to the possibilities of improvement there. That is where it will affect the output of motors and generators to the greatest extent.

J. D. Ball: The analysis I made was intended primarily for the purpose, not of showing it was absolutely correct, but to

point out the fact that a great deal of investigation has been done along the lines of this analysis, which has applied to our known materials, and therefore if this analysis is not correctly applied to this other material, it is necessary and interesting from the standpoint of a physicist to know it. I do not assume the analysis is absolutely correct for this material. It simply means one of two things—either the tests given are not correct according to the analysis or the analysis is wrong. We know the analysis is right for all material we have known up to date. It is very interesting to know if this analysis should not apply for this new material.

C. W. Burrows and R. L. Sanford (by letter): Mr. Yensen has pointed out the very marked influence of strain on values obtained in magnetic measurements. Similar strain effects have also been noticed both by us in our work, and also by other investigators. This strain effect seems to be accentuated in the high permeability material. He also points out the possibility that the correction to be added to the observed value of magnetizing force due to the current in the compensating coils of the Burrows permeameter should be greater than the calculated value. This point is well taken. The magnetizing force which the compensating current exerts is not constant throughout the space enclosed by the center test coil but it is a minimum at the center of the coils and greatest where the end turns are located. Consequently the calculation of the force at the center must necessarily give a value which is too low. The original description of this method was written at a time when permeabilities of 20,000 were unknown and it was supposed that this correction would not have to be applied. When correction must be made for the magnetizing effect of these end coils, the exact correction factor must be obtained experimentally, by measuring the magnetizing flux in the center test coil due to a given current in the compensating coils. Experimental values have been obtained in coils of approximately the same constants as those used by Mr. Yensen and the results show that the correction should be greater than that indicated by the calculations, though not so much greater as would seem to be indicated in the paper. This may be attributed to the fact that the assumptions made in the calculations are not fully met, and also to the effect of the yokes. In the case of coils 30 cm. long, the correction as calculated was 0.093 times the current in the compensating coils, while the experimental value was approximately 0.11 for the coils alone and 0.14 with the yokes in place but without test specimens.

One point that has very great influence on the accuracy of magnetic measurements on straight bars is the degree of magnetic uniformity of the specimen along its length. All precision methods for magnetic measurements on straight bars assume uniformity along the length of the specimen. If this

assumption is not met, errors are introduced which are impossible to calculate or eliminate and may be of considerable magnitude. It is therefore important that bars which are to be used as standards for the comparison of different methods or whose properties it is desired to measure with great accuracy should first be examined for magnetic uniformity.

Uniformity measurements are made at the Bureau of Standards by observing the distribution of magnetic leakage along the length of a specimen when it is magnetized between the poles of a suitable electromagnet. A double test coil, the two halves of which are wound oppositely and at a fixed distance apart, is slipped over the bar. When this is connected to a ballistic galvanometer and the magnetizing current is reversed, the galvanometer deflection is proportional to the difference in flux between the points under the two halves of the test coil, or what is the same thing, to the magnetic leakage over that region. Readings are taken with the coil in different positions along the length of the bar and the results plotted as in Fig. 5. Experiment has shown that if the bar is magnetically uniform the leakage, except for points near the ends, will be represented by a straight line with a certain slope, depending on the hardness of the material, passing through zero at the middle point of the bar. Plotting the slope of this line, which is the leakage per cm., gives for a uniform bar a straight line parallel to the axis except very near the ends, where the leakage is affected by the pole of the electromagnet. This is shown in the first curve. If there are magnetically hard or soft spots in the bar they will be indicated by deviations from a straight line. An increase in the leakage per cm. indicates that the test coil is approaching a hard spot, while the approaching of a soft spot is indicated by a decrease in leakage.

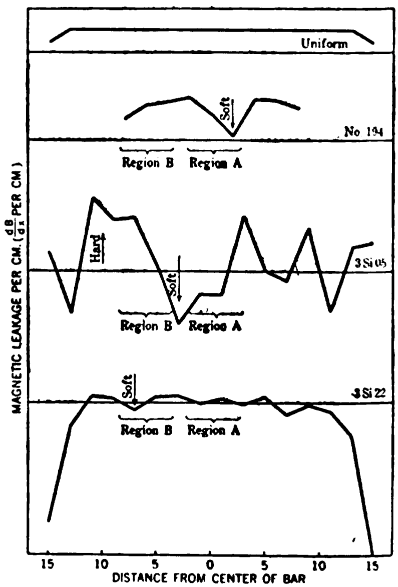


Fig. 5—Distribution of Magnetic Leakage per cm. for Four Bars

The first is uniform; No. 194 has a soft spot near the middle. 3 Si 05 is very far from uniform and 3 Si 22 has soft spots near the ends.

An example of the location of such a magnetic non-uniformity is shown by the second curve in Fig. 5, and its effect on the normal induction measurements is given in Fig. 6. The ex-

amination for uniformity shows a soft spot near the middle of the bar. This bar is about 35 cm. long. When it was measured in coils 20 cm. long and with the test coil over the middle region of the bar, the curve obtained was the one marked Region A. When the bar was moved over so that one end was flush with the yokes the curve marked Region B was obtained. The per cent difference in magnetizing force required to produce the same induction reaches a value in this case as high as 15 per cent. A detailed description of this method of examination for magnetic uniformity and the effect of non-uniformities on magnetic measurements is to be the subject of a paper by one of the writers.

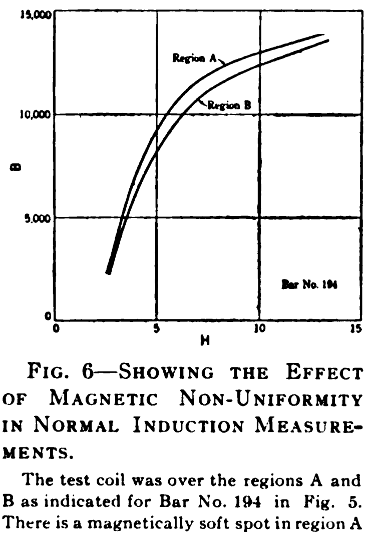


FIG. 6—SHOWING THE EFFECT OF MAGNETIC NON-UNIFORMITY IN NORMAL INDUCTION MEASUREMENTS.

The test coil was over the regions A and B as indicated for Bar No. 194 in Fig. 5. There is a magnetically soft spot in region A

Mr. Yensen has very kindly loaned to the writers two of his iron-silicon bars and they have been examined for uniformity with the results indicated in Fig. 5. The bars were marked 3Si05 and 3Si22. In the figure, uniformity curves are given for a uniform bar, for bar No. 194, the results for which are shown in Fig. 6, and for the two bars 3Si05 and 3Si22. It is readily apparent that 3Si05 is very non-uniform. Bar 3Si22 is not so bad but still is far from uniform. In order to gain an idea of the effect of these non-uniformities, measurements were made in coils 20 cm. long so that the test coils could encircle different regions of the bars. These regions are indicated in the figure. The results obtained are given in the following table.

Sample	*H*, for *B* = 10,000.		Per cent difference in *H*.
	Position *A*.	Position *B*.	
194	5.47	6.28	15.
3Si05	0.32	0.38	17.
3Si22	0.37	0.34	8.

It will be seen that the values are in agreement with what is indicated in Fig. 5. For No. 194 in position *A* the test coil

is over a soft spot and consequently in this position a higher permeability is shown. For 3Si05, position A is over a soft region and position B over a harder region and the indication is for a higher permeability at A than at B. In 3Si22 the conditions are reversed as there is a soft spot at B and consequently a higher measured permeability.

These results are to be expected from a consideration of the fact that these hard spots and soft spots with the resulting leakage will cause consequent poles which in general cannot be neutralized by compensation. These poles exert magnetizing forces on the specimen, varying according to the nature, position and extent of the non-uniformities, which can neither be calculated nor eliminated. It would not be surprising therefore to obtain with such bars different values, even when measured by the same method, if the constants of the apparatus, especially the location and extent of the test coils, are different.

T. D. Yensen: In the first place, Mr. Spooner asked regarding the possible connection between magnetic permeability and large crystals. I do not think from the results we have obtained that we can say that there is any such connection. I would like to call your attention to the photomicrographs. You will notice in Fig. 18c, the photomicrograph of pure iron exhibits very fine crystals after the 1100 deg. cent. annealing. The crystals from the previous annealing have been broken up into comparatively very fine crystals. You will also notice that this is the case with all the low silicon alloys, containing less than 1 per cent silicon. Passing on to Figs. 23 and 26, representing the 3.4 per cent alloy, it is seen that this alloy has very large crystals, but it has nevertheless nearly as high a minimum permeability as any of the alloys. Figs. 27c and 28c, representing the highest silicon alloys, exhibit crystals that are just as large, if not larger than the crystals shown in Fig. 23, but the magnetic permeability is very much lower than the permeability of the alloy represented by Fig. 23. Summarizing this, we find that of the two alloys having the highest permeability, containing 0.15 and 3.4 per cent silicon, respectively, one of them has very fine crystals (the low silicon alloy), while the other has very large crystals (the 3.5 per cent alloy). Thus, as far as this research shows, there is no connection between the crystal size and the magnetic permeability. This same statement might also be made regarding hysteresis.

In view of the unprecedented results obtained with regard to the magnetic properties of the alloys described in the paper, it was deemed desirable to test a few alloys in the form of rings. As the ring method is the old established method of magnetic testing, and as this method required no compensating or other auxiliary windings to cause uncertainties, the evidence obtained with such test pieces would naturally be more convincing than results obtained by any other method. On the other hand,

it has been shown by Richter[1] and Lloyd[2] that the magnetic induction in a ring specimen is not uniformly distributed, but that it is crowded towards the inside of the ring. The variation is greatest near the steepest part of the magnetization curve, where the maximum permeability occurs, and may here amount to as much as 100 per cent for high permeability material. Consequently it is impossible, with ring specimens to measure the maximum permeability, and this should be borne in mind when comparing the results obtained by the two methods.

The dimensions of the rings used are shown in Fig. 7.

With these dimensions the true magnetizing force, as shown by Lloyd and Richter, is

$$H_0 = 1.0009 \frac{2NI}{10R_0}$$

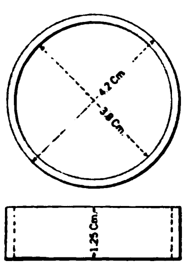


FIG. 7—RING SPECIMEN

Where R_c = mean radius = 2.0 cm.
N = total number of turns = 100
I = magnetizing current in amperes

Hence by using $H_0 = 10I$, the error introduced is less than 0.1 per cent.

The secondary winding consisted of 100 turns of No. 30 B. & S. wire wound next to the ring and connected directly to the Grassot fluxmeter. With this arrangement

$$\Delta B = 400\ D$$

where ΔB = change of average flux density in ring in gausses
D = deflection of fluxmeter.

Three rings were prepared all containing approximately 3 per cent silicon. From No. 3Si39, one ring was machined directly out of the ingot as it came from the melting furnace, while another was made from the remainder of the ingot after forging it. The latter was imperfect, however, and was discarded. The third ring was made from No. 3Si40 after forging the ingot, and the remainder of the latter was then forged into a rod to be tested by the Burrows method.

The specimens were first tested in the original state, unannealed. The windings were then removed and the rings and the rod placed in the annealing furnace and annealed in vacuo, the rod occupying the space along the axis of the tube. The maximum temperature to which the rod was subjected was 1100 deg. cent., but the rings were heated to a somewhat higher temperature as they occupied a space nearer the heating element, their axes coinciding with that of the rod. The speci-

1. Electrotech. Zeitschr. 24, p. 710; 1903.
2. Bull. Bureau of Standards, Vol. 5, No. 3, Reprint No. 108, 1909.

TABLE X.

COMPARISON BETWEEN THE RING METHOD AND THE BURROWS METHOD OF MAGNETIC TESTING

Test Piece.		Silicon content per cent.	Maximum permeability	Density for Max. Permeability gausses	Permeability		Hysteresis loss ergs per cu. cm. per cycle		Coercive force gilberts per cm.		Retentivity gausses		Spec. elec. resistance micr-ohms	Remarks
					for B = 10,000	for B = 15,000	for B = 10,000	for B = 15,000	for B = 10,000	for B = 15,000	for B = 10,000	for B = 15,000		
	UNANNEALED													
3Si39	Ring-made from Ingot..	3.19	2,000	4000	1,600	405	955	1130	0.45	0.45	1000	1,000	....	Tested by Ring method
3Si40	Ring-made from forging	2.96	3,000	3000	1,470	485	1305	1540	0.50	0.50	2500	2,500	....	" " " "
3Si40	Rod -made from forging	2.96	2,350	4000	1,210	545	3130	4450	1.00	1.00	4800	4,800	44.75	" " Burrow's "
3Si25	Rod -made from forging	3.40	3,000	3000	1,065	476			Not tested.				48.5	" " " "
	ANNEALED													
3Si39	Ring-made from Ingot..	3.19	32,000	8000	28,600	583	340	577	0.10	0.10	7320	9,600	....	Tested by Ring method
3Si40	Ring-made from forging	2.96	36,200	8000	31,200	962	337	757	0.10	0.10	7600	11,000	....	" " " "
3Si40	Rod -made from forging	2.96	72,600	9000	71,400	2500	254	926	0.085	0.16	9400	13,600	44.75	" " Burrow's "
3Si25	Rod -made from forging	3.40	63,300	7000	46,500	2030	280	1025	0.085	0.15	9000	12,400	48.5	" " " "

mens were cooled at the standard rate, namely 30 deg. cent. per hour.

The results are shown in Table X. In this table are included the results for rod No. 3Si25 from the main part of the investigation.

With regard to permeability the results show that in the unannealed state the two methods of testing agree very well. In the annealed state, however, the maximum permeability obtained for No. 3Si40 by the Burrows method is twice that obtained by the ring method. The latter method, however, as has been stated above, does not measure the maximum permeability, on account of the non-uniformity of the flux distribution, and in view of the results shown in Table VI, it is probable that the Burrows method gives too high a maximum permeability. Making allowance for possible differences due to material and heat treatment as well as mechanical treatment, it seems probable from these results that the true maximum permeability is in the neighborhood of 50,000. That the permeability for $B = 15{,}000$ is so low for the ring specimens may be partly due to the fact that the rings were annealed at a higher temperature than was the rod. It was shown in Figs. 14 and 15 of the paper, that with a silicon content of 3 per cent for $H = 20$ the flux density, after annealing at 900 deg. was 16,000, while after annealing at 1100 deg. it was only 15,600. A corresponding decrease in this region may consequently be expected also for higher annealing temperatures. This point is further borne out by the results obtained with the ring made from the ingot 3Si39 without forging. This ring may be considered as having been annealed at the melting point of the alloy. Its permeability at $B = 15{,}000$ is only 583 as compared with 962 for the ring made from 3Si40 after forging.

Turning now to the hysteresis loss it is found that in the unannealed state the loss in ring No. 3Si40 is less than half the loss in the rod. As the two methods are known to be equally reliable in this case the difference must be attributed to the fact that the rod was forged much more than was the ring. That this is the cause becomes evident from the result obtained for ring No. 3Si39 that was not forged at all, as this shows a decidedly lower hysteresis loss even than ring No. 3Si40. After annealing, the loss for $B = 10{,}000$ is shown to be less for the rod than for the ring, while for $B = 15{,}000$ the reverse is the case. The coercive force for $B = 15{,}000$ is 60 per cent larger for the rod than for the ring, while the retentivity is also lower for the ring.

These results seems to point towards the following conclusions: For such high quality material as that described in this paper the Burrows method gives too high maximum permeability and too high retentivity. For low densities the hysteresis loss obtained is low, while for medium and high

densities the coercive force and consequently also the hysteresis loss is too high.

While these rings were prepared for the purpose of verifying the results given in the main part of the paper, the results can not be dismissed without calling especial attention to the results obtained with the ring made from the ingot No. 3Si39 without forging. Unannealed this ring has a retentivity of only 1000 and the hysteresis loss for B = 15,000 is only 1130 ergs. per cu. cm. per cycle, not much above the value found for the best rod after annealing at 1100 deg. cent. After annealing the ring at 1100 deg. the hysteresis loss for B = 15,000 drops to 577 ergs. This value is less than $\frac{1}{6}$ of the corresponding value for the commercial 4 per cent silicon steel.

With regard to the hysteresis loss, Mr. Ball bases his conclusions on the assumption that the Steinmetz law, $h = \eta B^{1.6}$ holds for any iron alloy under any condition. That this assumption is not warranted even for some of the ordinary iron alloys is admitted to some extent by Mr. Ball himself, and is also shown by data recently obtained by various investigators. Paglianti,* for instance, has shown that for commercial silicon steel the hysteresis coefficient, η, may vary as much as fifty per cent for the same material for different values of B, on the assumption that the exponent for B is 1.6. Consequently, I do not see how any conclusion based upon the above formula can lay claim to absolute reliability. However, judging from the results of the comparative tests, as given above for ring and rod specimens, it is safe to say that the hysteresis losses for the vacuum alloys as given in the paper are too high for B_{max} = 15,000 but too low for B_{max} = 10,000. By making such corrections the values for the hysteresis losses will be found to follow Steinmetz's law more closely than indicated by the results given in the paper.

Regarding Mr. Ball's analysis by the reluctivity method, I wish to say that he has chosen a rather unfortunate part of the magnetization curve upon which to base his calculations. In the first place, the densities given in the tables for maximum permeability were not intended for use in accurate calculations, but rather to show the approximate location of the maximum permeability points. In the second place, Mr. Ball makes use of this maximum permeability point and of the data for B equals 10,000 only, in spite of the fact that these two points in most cases lie very close together. Consequently, any error in these two points is greatly magnified in the final values obtained by Mr. Ball for indicated saturation. Finally, Mr. Ball completely ingores the statement, repeatedly made in my paper, that in all probability the maximum permeabilities given in the paper are somewhat exaggerated, as corrections have been made according to theoretical calculations only. It was stated that experimental evidence seemed to indicate that

*Metallurgie, Vol. 9, p. 225, 1912.

errors as high as 20 per cent may have been caused by the compensating current of the permeameter. It would have been far better if Mr. Ball had chosen values from Figs. 14 and 15 upon which to base his calculations. In these figures corresponding values of B and H can readily be read off for H equals 0.3, 0.5, etc., up to H equals 200, furnishing a great deal of data that could have been used for the reluctivity calculations. If Mr. Ball had made use of these data he would, no doubt, have arrived at more consistent results.

In reply to Mr. Ball's question regarding aging, I may say that at ordinary temperatures no aging has been observed. Higher temperatures have not been tried.

No tests have as yet been made by us with the vacuum alloys in the form of sheets, but such tests are contemplated in the near future.

John D. Ball (by letter): In Mr. Yensen's closing discussion I note in his explanation he says that the values of the inductions at which the maximum permeability values occur are only supposed to be approximate and do not represent actual values. In this case as the point of maximum permeability is close to B = 10,000 undoubtedly the analysis for ultimate saturation value which I made is not to be depended upon to too great an extent. The analyses for hysteresis, however, are definite. Taking the last results which Mr. Yensen has written and calculating the values of η, and taking the ratios of losses at B = 15,000 divided by B = 10,000, we find results as follows:

	Hysteresis		η		
	B = 10,000	B = 15,000	B = 10,000	B = 15,000	Ratio
UNANNEALED					
Ring Ingot......	955	1130	0.38×10^{-3}	0.235×10^{-3}	0.62
Ring Forged.....	1305	1540	0.52	0.320	0.615
Rod Forged......	3130	4450	1.248	0.927	0.745
ANNEALED.					
RingIngot.......	340	577	0.1353	0.120	0.89
RingForged.	337	757	0.1342	0.158	1.17
Rod Forged......	254	926	0.1010	0.193	1.91

For the unannealed iron we find that the hysteresis loss increases slower than given by the 1.6 law, whereas in all other investigations tests have shown that the loss apparently increases faster.

The results for the annealed rod are unusually high, as I pointed out in my discussion. The results obtained on the annealed ring from the forging are entirely consistent with our experience with other materials. It would be interesting indeed to find

an explanation for these unusual low increases of hysteresis losses at $B = 15{,}000$.

T. D. Yensen (by letter): Regarding the values given for the commercial silicon steel to which Mr. Ball did not agree, I should like to add that these values were obtained about two years ago by means of our original permeameter in connection with a ballistic galvanometer, before the Grassot fluxmeter was adopted. It was thought that the measurements thus made were sufficiently accurate for material of comparatively low permeability. On account of Mr. Ball's remarks, however, it was considered desirable to repeat these tests on the original rods with the fluxmeter. The results thus obtained are shown in Fig. 8. From this figure it is seen that the

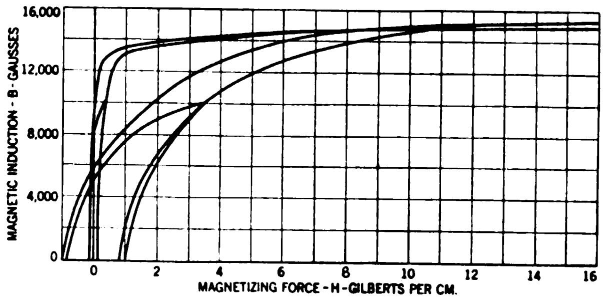


FIG. 8—COMPARISON BETWEEN VACUUM IRON AND COMMERCIAL STEEL, BOTH CONTAINING BETWEEN 3 PER CENT AND 4 PER CENT SILICON. THOROUGHLY ANNEALED. VACUUM IRON—RING SPECIMEN FROM ALLOY NO. 3 SI 40 CONTAINING 3 PER CENT SI.

	Vacuum Iron	Commercial Steel
Hysteresis Loss for $B_{max} = 10{,}000$; ergs per cu. cm. per ~	356	2160
" " $B_{max} = 15{,}000$; " " "	709	4290
Exponent, x in $H = \eta B^x$	1.68	1.69
Coefficient, η, in $H = \eta B^x$	0.0000682	0.000376
Spec. Elec. Resistance, microhms	44.75	50 8

hysteresis loss for the commercial silicon steel for $B_{max} = 15{,}000$ is considerably higher than shown in Fig. 16 of the paper, and the values for $B_{max} = 10{,}000$ and 15,000 follow the Steinmetz law very closely, thus agreeing with Mr. Ball's experience regarding commercial silicon steel.

The results obtained by Dr. Burrows and Mr. Sanford are of great interest as they have a direct bearing upon the results given in the paper. They find that the corrections for such coils as we have used, as determined experimentally, should be 0.14 times the compensating current with the yokes in place but without test specimens. I take this to mean that the correction to be added to H_t, expressed in gilberts per cm., should be 0.14 times the value of the compensating current

expressed in amperes. If this assumption is correct the correction to be applied in the case the compensating current is 30 times the main magnetizing current should be 4.2 per cent. Mr. W. A. Gatward and myself have recently made tests, similar

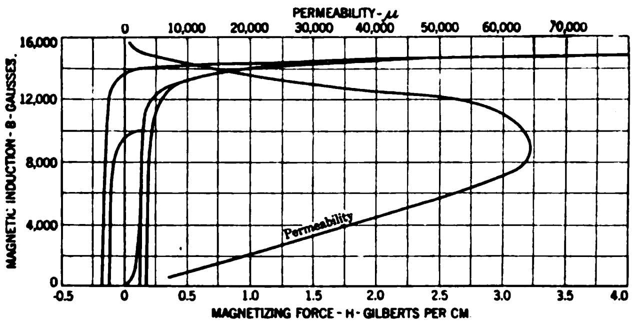


FIG. 9A—ALLOY NO. 3 SI 40, ROD SPECIMEN. ANNEALED AT 1100 DEG. CENT. TESTED BY BURROWS METHOD. CORRECTIONS MADE ACCORDING TO EXPERIMENTAL RESULTS.

Hysteresis Loss for B_{max} = 10,000; ergs per cu. cm. per ~	....	360
" " B_{max} = 15,000; " " "	....	880

to the above, with our apparatus, and these indicate that the correction should be 0.55 times the value of the compensating current, or four times the value given by Dr. Burrows and Mr. Sanford. For a ratio of 30 the correction according to our

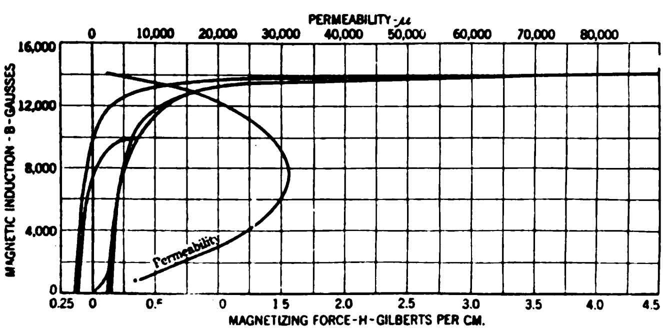


FIG. 9B—ALLOY NO. 3 SI 40. RING SPECIMEN. ANNEALED SLIGHTLY ABOVE 1100 DEG. CENT. TESTED BY RING METHOD. NO CORRECTIONS MADE.

Hysteresis Loss for B_{max} = 10,000; ers per cu. cm. per ~	....	356
" " B_{max} = 15,000; " " "	....	709

tests should be 16.5 per cent, agreeing fairly well with the results given in Section I of the paper under "Magnetic Testing," arrived at by a different method. By making this correction for rod No. 3Si40, containing about 3 per cent silicon, the revised hysteresis loop is as shown in Fig. 9A.

Attention should be called to the extreme difficulty of getting exact values for the nearly vertical parts of these curves. This refers particularly to the hysteresis loops, and liberal allowance should be made for this in making comparative calculations. However, a comparison between the results obtained by the Burrows method, as shown in Fig. 9A, and those recently obtained by the ring method, as shown in Fig. 9B, brings out very clearly that the Burrows method, even after making the above corrections for the compensating currents according to the experimental results, gives too high residual magnetism, and—for high inductions—too high coercive force. The result is that the hysteresis loss for B_{max} = 15,000, as measured by the Burrows method, is likewise too high. It thus appears that, until it has been definitely determined how to make corrections in testing high permeability material by the Burrows method, it is safer to base the final conclusions upon results obtained by means of the ring method.

In Fig. 8, therefore, a comparison is made between the vacuum silicon-iron and the commercial silicon steel, based upon the results obtained by the ring method in the case of the vacuum iron. The results for the commercial steel were obtained by means of the Burrows method, as it has been shown that this method is perfectly reliable for ordinary material. Fig. 8 then should give as true an exhibit of the actual difference between the vacuum product and the commercial steel as it is possible to obtain at the present time with the present means at our disposal. From the results there shown it is found that the hysteresis loss for the vacuum iron is only $\frac{1}{6}$ of that for the commercial steel both for high and for low densities. The hysteresis exponent, as calculated from these values, is 1.68 for the vacuum iron and 1.69 for the steel, an unexpectedly close agreement.

Tests are at present being made on the vacuum-silicon-iron in the form of sheets of varying thickness, the specimens being in the form of rings made up of a number of punchings. It is hoped that the results of these tests will be available in a short time.

Discussion on "The Principles and Systems of Electric Motor Control" (Knight), New York, December 10, 1915. (See Proceedings for December, 1915).

(Subject to final revision for the Transactions.)

Bassett Jones: It seems to me that Mr. Knight makes many statements as though they were indisputable facts, that are really subjects requiring careful determination in each case of control application. My experience with controllers has led me to the conclusion that the question of copper vs. graphite contacts is of this nature. The answer, it seems to me, will depend upon the mode of operation of the motor control and the character of its service. Nor do I believe that it is always essential that a multiplicity of separately operated contactors be employed. There are other statements in the paper which are open to the same form of question.

My experience with motor control has related largely to building equipment. In a building such as a hotel, for instance, motors will be used for all kinds of services. In some cases series motors are advisable; in some cases compound-wound motors give the most advantageous service, and in many cases, shunt-wound motors have characteristics which are peculiarly useful and these motors have a large range of sizes in the same installation. Usually the architect writes the specification which, in all cases, does not even indicate more than the mere fact that a motor is required. Such specifications are turned over to heating and plumbing contractors, etc., who proceed to purchase motors and controllers where they can best do so from the viewpoint of first cost. They will buy motors from one manufacturer and not always of the same type, and controllers from other manufacturers and not always of the same make, so that in most buildings there is an extraordinary diversity of motors and controllers, and in instances this diversity even occurs in the case of motors and controllers used for similar purposes. The result is that great confusion exists. The wrong type of motor is frequently purchased and the wrong type of controller for this motor and the service which it has to perform, so that it is rare to find an installation in which continuous trouble does not occur in one form or another. The electrician at the building has to carry a stock of supplies for each make of controller and each make of motor installed, and he is very rarely properly instructed so that he can purchase the right sort of material and renewal parts.

That this is not an exaggeration can be indicated by one of many instances with which I am familiar. This case involved a centrifugal pump working under intermittent service on closed house tank duty with 160 ft. head and a check valve placed in a discharge line. The equipment was not provided with any automatic by-pass or any device to take care of the reduction in head should fire connections be taken off below the tank level. The pump was operated by a three-phase 20-horse power

squirrel cage motor which was controlled by an unbalanced resistance starter. There were three material defects in the system; first, the arrangement of the piping was wrong; second, the type of pump for the duty required was wrong; third, the type of motor was wrong; and fourth, the controller was of the wrong type to use with this motor under the conditions under which it had to operate. A fifth error was in the wiring of the controller, which was so connected that in addition to having but two resistances in two of the three phases, the resistances themselves were unbalanced. The result was that when the motor started automatically, its in-rush current was somewhat over seven times its running current, resulting in an extraordinary disturbance in the service lines, which indeed was felt as far away as the central power station, fifteen miles from the motor installation, and caused a slowing down of all of the a-c. elevators in the immediate neighborhood.

This entire trouble could have been avoided if the proper specifications had been drawn for the equipment or even if a little common sense has been used in purchasing the material. The plumbing contractor who made the installation cannot be blamed, for he was not familiar with electrical appliances.

The moral to be drawn is that the manufacturers do not issue the proper information in such form that men such as this contractor can avoid such difficulties.

I have studied most of the literature on controller and motor applications issued by manufacturers, and have yet to find any material of this sort that gives the right kind of instructions for the selection of motors and controllers and for ordering them.

I came to this meeting tonight with the hope that I would hear something said that would tend to alleviate this difficulty, and I find the representative of one manufacturer making emphatic statements with regard to the details of controllers which are immediately and quite as emphatically denied by the representative of another manufacturer. As a matter of fact, I consider both of them are more more or less right, but the result of the discussion, in its effect on those who are trying to purchase controllers, is disastrous.

Edwin J. Murphy: While hearing Mr. Knight's paper read, I noted several points that might be brought out. One relates to the limitations of manual control as compared with magnetic control. I have in mind the rapid evolution in the railway field, where the manual control reached its limitations. I believe that the largest drum type controllers ever built were used in the Baltimore & Ohio tunnel electrification, where the power to be handled required an enormous controller. The limit to the size of manually operated controllers would be set by the physical strength and endurance of the operator. This particularly applies to many steel mill operations, wherein the motors are frequently reversed. In such applications it is practically imperative to adopt the magnetic type of control using the contactors.

Referring to the design of such contactors, a great deal depends upon the duty for which they are required, and while these devices to some extent perform the functions of the usual circuit breaker, a satisfactory design of the latter would not be suitable as a contactor. I refer particularly to the contacts. The average circuit breaker is equipped with a brush contact for carrying the current in conjunction with carbon arcing contacts. This arrangement is entirely satisfactory as a safety device and in most cases circuit breakers are not operated more than once a week. The operating conditions for contactors are entirely different and far more severe.

In many applications the contactors must open and close heavy currents many times per minute for long periods. We have found that solid copper contacts are best adapted for severe operating conditions and that brushes wear out and give trouble under similar conditions; this also applies to auxiliary carbon arcing contacts, with added objection due to the fragility of the material. Very massive carbon contacts can be used in certain special applications where the normal current of the motor is small with high accelerating peaks of short duration. The extremely high resistance of carbon is one of the practical limitations in this case. Carbon contacts are frequently used in elevator control where conditions are favorable.

Mr. Knight mentions the magnetic blow-out used in contactors and points out the necessity of keeping the arc away from the insulating plates of the chute, which otherwise would be quickly destroyed. It may be interesting to note that the sound accompanying the rupture of heavy currents will indicate the efficiency of blow-out in this respect. An inexperienced person would be led to suppose that a sharp report would mean that the circuit was rapidly opened, hence efficiently. This sharp report really means that the arc has been blown against the chute or baffle. A dull roar of relatively short duration shows that the blow-out is arcing properly. With direct current, the first-mentioned noise may be compared to the sharp crack of a rifle; but a noise like the discharge of a shot gun indicates proper action.

I agree with Mr. Knight concerning the design of contactor magnet coils that require auxiliary series resistance. This arrangement means extra interlock contacts and adds another complication and possible source of trouble.

Referring to the a-c. contactors mentioned, it is rather surprising to note the difference in the results obtained in operating a well designed air break contactor, equipped with a magnetic blow-out, and an oil-immersed contactor of similar capacity. A high-voltage air break contactor makes a great noise with a spectacular arc and one would think that the life of the arcing contacts and adjacent parts would be very short and the quietly acting oil-immersed contactor would have the advantage on these points. As a matter of actual experience, with well designed contactors breaking 2300 volts, 300 to 400 amperes,

the life of the arcing tips of an air break contactor might be five or ten times that of the tips in the oil-immersed type.

The oil breaker or oil-immersed switch is certainly a very reliable device and gives good service in the proper fields. Where large power is very frequently interrupted, the high-voltage air-break contactor is more suitable.

With reference to the counter e. m. f. system of control, there is one serious limitation where a large number of accelerating contactors are necessary. In such cases, the last contactor to close must be operated at a voltage very near the line voltage. If the line voltage is not constant, it might fall below the point where this contactor is set to close and the last section of starting resistance may remain in circuit indefinitely. The change in the resistance of the contactor operating coils due to normal temperature rise will aggravate this trouble.

The current-limit control system is on the whole the most satisfactory for starting a variety of loads. The same panel with identical adjustment will start a motor having so little inertia load as to reach normal speed within a few seconds, and also start a motor with sufficient inertia load to require thirty seconds to reach normal speed. This system is not sensitive to line voltage fluctuations.

The time-limit control would be all right if load conditions were always invariable, but this is seldom met in practise. In the case of fire-pump installations, where it is absolutely necessary to get the motor up to speed regardless of possible damage, the time-limit control is suitable.

The use of dynamic braking for quickly bringing the motor and load to rest is a very valuable feature and widely used, in reversing planer control and similar applications.

In closing, I may say that those who are familiar with steel mill apparatus and machine tool control, are aware of the rapidity with which control panels must often operate. There are extreme cases where a motor must be reversed as often as thirty times a minute for long periods. This means that the line contactors operate thirty times per minute and the accelerating contactors operate sixty times per minute. This is a very severe mechanical and electrical test of the control devices and in many cases this is further aggravated by the presence of gritty dust in the surrounding air.

W. I. Slichter: The ability of the modern control system to control the acceleration, direction and operation of large size motors, to protect these motors from overloads and false steps, is really wonderful. The problem is very intricate and complex, and it is, therefore, probably natural that the apparatus used should also be complex. The systems have developed so that they may be put in the hands of the most ignorant operators and, on account of the fool-proof properties, prevent any damage resulting from improper handling. But in order to achieve this very desirable purpose, some of the installa-

tions are made in such a way that it takes a very experienced and expert specialist to install or repair the apparatus or even to follow the diagrams and understand the functions of each part.

While I am not prepared to state absolutely that a more simple system is possible, yet on the principle that the simplest method is always the best method, I wish to put in my plea for a consideration of the question whether all the protective and regulating devices usually included in the control systems are so essential that they really warrant the complexity introduced; and second, whether a uniform system of conventional symbols might not be recommended or adopted by the Institute with advantage to all.

The series contactor is one means of simplifying the control by doing away with a number of the relay circuits and interlocks, and I would like to ask to what extent the series contactor is being used in commercial installations and what are the chances of its becoming the universal switch in the accelerating operation.

The design of a control system which shall start the motor, limit the current to a given maximum and bring the motor automatically up to speed in the minimum time compatible with the allowable upper limit of current is a very nice problem, involving a careful theoretical calculation of the resistance to be used on each step and a nice adjustment either by time or current value to determine the transition from step to step. It is a matter which requires an ingenious arrangement of circuits, several of which are described in the paper under discussion, and of these it appears to the writer that the method using series relays offers great possibilities of reducing the complexity of the wiring and thereby the chance of trouble and the cost of maintenance.

The control of a-c. motors usually requires the use of a contactor energized by alternating currents, which is a problem presenting many difficulties, first, on account of the liability of chattering of the contactor with the pulsating flux; and second, on account of the fact that an a-c. solenoid supplied with a constant voltage has a constant value of flux requiring a very large current when the contactor is open and a small current after the contactor is closed. As far as the design of the contactor itself is concerned, this brings about a condition in which the current is large during short periods of time and small during continuous operation, resulting in lower heating and economy of material, but great sensitiveness to voltage variation.

In regard to the resistances used, I shall be glad to hear what progress is being made in ventilating and cooling the resistance proper, as so much improvement has been made in the ventilation of electrical machinery of late that it seems natural to expect that this knowledge should be applied to

the reduction in amount of material used in resistors, not only to reduce the first cost, but particularly to reduce the weight and space occupied by the apparatus.

From some tests on copper, steel and brass contacts in my own experience, I can endorse the author's statement that copper is the best for contact, and that for quick action or for a confined space, carbon auxiliary contacts are not desirable.

In connection with the subject of dynamic braking, I have met with several installations in which the resistance shunted across the armature is kept in series with a higher resistance across the line arranged in potentiometer connection, and would like to ask the benefit of this arrangement.

Where we have to start and stop a large mass frequently, as in a mine hoist, it is quite a problem to take care of the kinetic energy. With dynamic braking we have the motor operating as a generator, short-circuited by a resistance, and a large part of the kinetic energy of the mass is liberated in the resistance and a small part liberated in the armature of the machine, which means a larger motor. This is not always appreciated by the customer or the operator. In plugging, the mass is stopped by reversing the motor, that energy is all liberated in the armature, and consequently we must have a very much larger motor. This matter of stopping the mass is of very great interest, and the dimensions of the armature of the motor to be used in that connection are very important.

F. B. Crocker: The term "control" as used in this paper seems to be confined to the automatic starting of motors.

Some quarter of a century ago I read a paper on the regulation of electric motors. I used that term in the generic sense and the paper almost entirely related to the variation or adjustment of speed. Now it is a question of starting motors. I think I can understand the reason. In those days to which I refer, a motor was a small device, with one single contact, and one switch of reasonable capacity could readily control all the current. We had no difficulty in dissipating the energy, a moderate rheostat would handle it, and one contact would stand the wear and tear. Now two things are necessary, one is the subdivision of the current, because the motors are so large, and the other is to limit that current, because the starting current is heavy, and must not exceed a certain maximum. Therefore the matter of control now is really one of starting motors and limiting the current by subdividing it between a number of contacts.

This paper does not go into the question of speed variation. In a quarter of a century, there has not been such a great deal of progress made in solving the problem of the variable-speed motor, that is, speed adjustment.

Of course this question of motor control with reference to

starting is a very practical question. We are not so very much nearer to a really satisfactory solution of the speed control in contradistinction to the current control, which is the principal point in the starting of motors.

The difficulty in starting, as in speed control, is that we have to provide in some way for the difference between the applied voltage and the low counter e.m.f. in the motor. It is really difficult to dispose of the amount of current that corresponds to that voltage. The obvious way is to take it up in a rheostat. That is what we used to do in those old days, and that is what we do now. Perhaps there never will be an entirely satisfactory solution of that problem, but it does seem, with the great advance we have had in twenty-five years, that we should have done better in solving this particular problem of handling this difference between the full running conditions of the motor and the low speed or zero speed.

All we do is to simply destroy the energy. That does not seem to be the efficient or scientific solution of the problem. The motor when it runs at full speed is an admirable machine, but running at low speed or starting to run, is a condition that we do not seem to have handled scientifically, although we have handled it practically with sufficient success to make it commercial.

J. H. Albrecht: Mr. Knight took up the question of the use of carbon on the contacts of magnetic contactors. The company I am connected with, on the larger sizes of contactors uses carbon or rather graphite for the initial contact. The chief objection to the magnetic switch, especially among steel mill men, has been the fact that it "froze", the common name for sticking or welding in the closed position. When you are handling small currents not in excess of 125 or 150 amperes there is not much danger of freezing, for several reasons. In the first place, the energy handled is small. In the second place, you do not require the stiff spring pressure necessary in handling large currents. Any well designed contactor in normal service will not freeze, *i.e.*, if the switch closes completely the proper design of the contact motion will allow the contactor to break itself free on opening. However, when you get a jogging condition the operator will throw his master controller and if he has made a false move he will reverse it instantly. As a result the contactor will start to close and may then have its magnet coil deenergized just as the initial contact is made. In the larger sizes of contactors you must have a fairly stiff spring pressure and it is a fact that if two pieces of copper are brought together in this manner with a stiff spring pressure back of them, there is a decided tendency to weld or freeze. If your initial contact is graphite to copper it will not weld, and that is our justification for the graphite contact.

We have done quite a lot of experimenting and have finally come to the use of a very dense, hard graphite which resists both the mechanical wear and the electrical wear very well, and it will stand up just as long as the copper contacts. The above, of course, applies only to the initial contact. In its final position the contacts roll over the graphite and on to a copper contact. The final contact, therefore, is between copper and copper and the graphite piece does not carry any current.

Regarding a-c. contactors in high-voltage work, we strongly advocate the air-break switch for very frequent service for the reasons which Mr. Knight has mentioned. Another reason is the fact that the air-break switch is open in construction and readily accessible for inspection. The operator can see at a glance what shape his contacts are in. In the case of an oil switch he must take the tank off to inspect the contacts and he will probably not do this until trouble occurs and forces him to make the inspection.

There is one point I want to bring out in connection with the use of the high-voltage air-break switch. In one of his illustrations Mr. Knight showed a mechanically interlocked set of reversing contacts and in another illustration an electrically interlocked set of contactors. That is, the coil current for the reverse switch was carried on a "butterfly" or interlocking contact on the forward switch. It has been our experience that neither an electrical or a mechanical interlock or a combination of both is satisfactory. It is satisfactory under normal conditions but under certain conditions it is sure to cause trouble. If there is a tendency for the arc to hang over, the opposite directional switch may close and cause a short circuit as long as the first arc is maintained. This cannot be avoided with the interlocking schemes outlined by Mr. Knight because the a-c. magnets are very quick-acting and the forward switch is very apt to be in the open position with the arc hanging on when the reverse switch closes. I believe many of the otherwise unexplainable peaks on hoist circuits using these controllers are due to the instantaneous over-lapping of the reversing contactors.

To get away from this condition we have developed what we call the drop-out relay. Two of these relays are used, the coil of each being in series with one or the other of the directional switches, consequently, in series with the arc. The relay on the forward switch carries the operating coil of the reverse switch on its contacts. The relay on the reverse switch in a similar manner controls the coil of the forward switch. The relay has a very low drop-out point and will hold up until the arc has actually been blown out and, of course, prevents the closing of the opposite switch until this has happened. We have found this to be a very valuable device, especially in rapid reversing service, as it absolutely prevents any overlapping of the directional switches.

Dr. Crocker in his remarks deplores the lack of progress in speed control and regulation of d-c. motors. Probably the most remarkable example of progress along these lines is the new electrically driven reversing blooming mill drive. We have recently installed for one of the large steel mills a 12,000-h.p., d-c. machine driving the main rolls. We use the variable voltage system of control, the motor is permanently tied in to the generator which in turn is driven by an a-c. motor equipped with slip regulator. The generator unit carries an extremely heavy flywheel on its shaft. By the proper functioning of the slip regulator the flywheel carries all the peak loads. The h.p. required at the mill spindle ofttimes reaches 15,000 h.p., and at the same time the line input to the a-c. end of the outfit is limited to approximately 1600 kw. The difference between the line input and the output at the mill spindle is, of course, supplied from the stored energy of the flywheel. We get a speed variation of from 0 to 120 rev. per min. by field control of the motor and generator. The reversal is obtained by reversing the polarity of the generator. The regulation is very good at all speeds and, of course, there are no rheostatic losses except the extremely small loss in the exciter circuit.

This application is also a very good example of what can be accomplished by dynamic braking. When the motor field is strengthened by pulling the master control handle to the "off" position the motor will regenerate through the generator circuit a current which sometimes rises as high as 6000 amperes. 6000 amperes at 600 volts multiplied by 2, as there are two machines on the shaft, gives a total energy of 7200 kw. returned to the line. This energy is not absorbed in any resistance but is returned to the generator and utilized in speeding up the flywheel for the next pass.

H. F. Stratton (by letter): I wish to speak briefly about another phase of electric motor control. I would like to emphasize some of the reasons responsible for the constantly increasing use of electric power. Mr. Knight touches on this subject in his opening paragraph when he says that one of the main reasons why the electric motor has superseded steam power, is the superior control features of the electric motor.

Examine the United States Census statistics and certain important conditions will be found. These conditions remain the same in principle and largely the same in magnitude whether they are examined from the standpoint of individual industries or from the standpoint of the total of all industries. The three conditions which I am going to mention I think are the most important aspect of modern manufacturing. They are; first: a large increase in wages per hour, and it is estimated by economists that during the last ten years average wages per hour have increased 30 to 40 per cent; second, a decrease in the item of wages expressed as a portion of the

selling price; third, a large increase in the investment in manufacturing equipment, and this increase is larger proportionately than the increase in output.

On one side we see labor demanding and getting more wages, shorter hours and greater expenditures in the interests of welfare and safety. We also unfortunately see labor protesting against the increased efficiency of labor; insisting that a man shall do, not what he can, but only what the average man can do.

On the other side, we see the combined efforts of millions of dollars spent for new equipment, and a large number of specialized thinkers struggling to increase production that profit may not be annihilated. Improved equipment is used that the workmen may produce more, or that a $3.00 man may displace a $4.00 man. Machinery is designed so that numerous operations are performed simultaneously, automatically, and rapidly. Manufacturing operations are planned and standardized, speeds and feeds are specified, in order that output may depend, not upon the initiative of the workmen, but upon the capacity of the machine. Material is routed to travel the least possible distance in its conversion from raw to finished products. The principle of the division of labor is carried to a degree of completeness heretofore apparently impossible. A condition is being approximated where many manufacturing operations are largely independent of the initiative and skill of the workmen.

I think it is along these lines of increasing productive capacity, that the properly controlled electric motor is finding a reason for its rapid extension. These points are mentioned to emphasize my contention that the proper development of control apparatus lies along the lines of increasing production and decreasing labor cost. I think electrical control apparatus incorporating these characteristics will advance in its application because it is genuinely progressive.

M. D. Goodman: In those cases where engineers object to copper contacts for magnet switches it is due mostly to an inertia rather than any sound engineering objections. For years the carbon contact has been used with moderate success. However, we can say that the carbon contact cannot be made to give satisfactory service for such applications where the switches operate thousands of times a day, as is the case in the steel mill service.

Within the last few years, the more progressive manufacturers of controllers have discarded the carbon contact and are now using copper to copper contacts with satisfaction. Of course, the contactors themselves had to be modified so as to give a quick make and break and sufficient pressure between the contacts. Furthermore, the rebound which would naturally occur when one contact touched the other, had to be gotten rid of or else they would arc on closing the switch.

One ingenious method of overcoming rebound is to insert a loose plug in the main contact arm. When the contactor coil is energized, the loose plug is drawn up to the core, drawing the arm with it. During a small fraction of a second after the loose plug has closed the magnetic circuit of the switch, the arm will vibrate, due to the reaction from the spring which is placed behind the stationary contact arm. However, the vibration of the arm is limited in amplitude by the loose plug of the arm so that the contacts cannot separate. Hence, no arc can be produced on closing the switch.

In reference to intermittent and continuous capacity shunt coils, Mr. Knight is of the opinion that the continuous capacity coil should always be used. I believe that both types of coils have their particular uses. In those cases where rapidity of operation is essential, as is required in steel mills, the intermittent capacity coil is better adapted for this service, because it allows the switch to be closed and opened more quickly. This advantage is of special importance on switches of large capacities, where the inductance in the continuous capacity coil would appreciably slow up the action of the switch, and therefore decrease production. In fact, in one mill the writer knows of, the controller had to be discarded, because it would not accelerate the motor quickly enough, even after all the relays were omitted and the cutting out of the armature resistance depended entirely on the consecutive operation of the shunt-wound accelerating contactors.

In regard to any objection to control circuit contacts, these have been developed to give a wiping action when they open and close. This adds considerably to their satisfactory performance. Furthermore, the particular type of protective resistance with which the writer is familiar gives practically no trouble.

Mr. Knight mentions the fact that he prefers time limit starters for such classes of machinery where the overloads during the starting period prevent a series contactor from closing. As Mr. Knight brings out, if a time limit starter is used and the motor is started under heavy overload, the circuit breaker will kick out after a certain portion of the armature resistance has been short-circuited. Recently an inverse time element overload relay has been designed, which allows full advantage to be taken of the current limit automatic starter for all classes of service and at the same time protects the starting resistance in the starter as well. With the inverse time element, this overload relay may be set at approximately full load current. With the inverse time element feature, this overload relay may be adjusted to keep closed for from twenty to thirty seconds with this load. The greater the overload, the more rapid will be the operation of the relay. Under these conditions, the starting resistance of the current limit starter will not be held in circuit long enough to do any damage,

if the motor load is so heavy as to prevent one or more of the accelerating switches from closing. At the same time, the relay will not open under normal accelerating conditions.

This inverse time element feature has been available for some time past, but it was to be had only in very expensive circuit breakers. Engineers will certainly be interested to know that an overload relay has been developed which meets the required conditions and can be obtained at a reasonable cost.

F. W. Gay: Control by voltage variation is frequently used in the case of large isolated installations, but has been somewhat lost sight of as a system for industrial plants. A few of us have had wide experience in the use of the multiple voltage system, and know that certain difficulties which were originally encountered are being overcome by the new systems of control which have come out in recent years.

The difficulties with the multiple voltage system in the old days were short-circuiting and arcing of the controllers when throwing over from one voltage to another. These difficulties have been largely overcome by the development of automatic current limiting switches, which protect both the controller and the motor, also new contact switches allow small master controllers to be used on large motors for switching from one potential to another. These improvements make the old multiple voltage systems much more practical, and it seems to me they merit greater development than has been given to them.

C. D. Knight: The aim of all control engineers is to simplify automatic control as much as possible. For the plain acceleration of d-c. motors, the series contactor is the simplest device. We have yet, however, to perfect an a-c. series contactor. Consequently we are obliged to adhere to the shunt contactors and series or time limit relays for the automatic acceleration of a-c. motors.

For adjustable-speed d-c. motors, we have the series field relay, which automatically brings the motor up to any predetermined speed above full field operation. I believe today, due to the numerous exacting applications of motors and control to various industries, that there are, by far, more adjustable-speed motors being installed than constant-speed.

I think the most complicated control that I know of today is the reversing planer equipment. This is entirely automatic in its action, the duty cycle being such that it may operate every three to four seconds, and in that time automatically accelerate the motor, at the end of the stroke cut it off, introducing dynamic braking, which stops it quickly, automatically reverse it, putting it through the same operation on the return stroke. This is naturally a very difficult duty cycle, resulting in thousands of operations a day.

For machine tool work, in general, I suppose it is safe to

say that 75 per cent of the machine tools are today being equipped with adjustable-speed motors. While with d-c. motors we have both armature and field control, in the case of the a-c. motors we have adjustable speed only in the slip ring type of motor in which we get the equivalent of armature control by introducing resistance in the secondary circuit.

There has been some argument raised in connection with the design of contactor tips. By examining Fig. 1 it will be seen that the contactor is so designed that the two solid contacts first come together at point *A*. As the contactor closes there is a rolling action over the surface of these two contacts, and when the contactor is entirely closed the current is carried at point *B*. When the contactor is de-energized, the same rolling action takes place, and the current is broken at point *A*. It is, therefore, impossible to carry current on the surface, which makes and breaks the current.

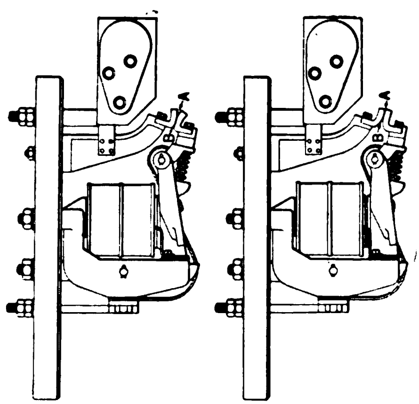


Fig. 1

There seems to be some misunderstanding about what we call a wipe and roll. Fig. 1 shows a rolling contact. Instead of having a rolling action, a wiping action could be introduced in which one contact rubs against the other,which might operate well when they are both smooth, but if at all rough an effect similar to rubbing two files together would be produced and would no doubt have a tendency to keep the contacts from closing sufficiently and result in their welding or freezing.

J. H. Albrecht: My opinion is that if they just come up to the point you designate at the top and are de-energized, and the contactor is allowed to fall open again, your rolling action does not help.

C. D. Knight: In case of severe duty where the contactor is liable to be de-energized before it is entirely closed, anti-freezing devices have been introduced, which to a certain extent create sufficient pressure to throw out the contactor

at point *A*. I believe the method you have in mind is to introduce graphite about the point marked *A* on the sketch so that when the contacts are entirely home you are carrying the current through the solid copper at the point marked *B*.

J. H. Albrecht: That is right.

C. D. Knight: All I can say to that is that I have yet to be convinced that the graphite or carbon will last as long as copper. Our practise of using solid contact tips wherever possible is based on a great many years' use of this same type of contactor on railway work. It has proved very reliable, and we have introduced it in many industrial applications and found it very successful.

Another question which has been raised is regarding the use of intermittent duty coils. I have known of cases where it was necessary when quick action was required to put 110-volt coils on a 220-volt circuit. In many of these cases, the coils are in service but a short time on reversing propositions, consequently do not overheat. I believe in cases of this kind intermittent coils can be used. The point I wished to bring out was that where we use a shunt coil and introduce resistance in series with it by means of an interlock, an interlock of this kind is more or less a dangerous proposition. Sometimes the interlock will open before the contactor is all the way home. This naturally reduces the current in the coil, resulting in a reduction of the ampere-turns necessary to close it. This means insufficient pressure on the contacts and is liable to produce undue heating and possible freezing.

Discussion on "Outline of Theory of Impulse Currents" (Steinmetz), New York, Jan. 14, 1916. (See Proceedings for January, 1916.)

(Subject to final revision for the Transactions.)

Charles P. Steinmetz: "Outline of Theory of Impulse Currents" is a continuation of the paper on the general equation of the electric circuit, read eight years ago. In the previous paper it was found that the general differential equation, which applies to every electric circuit or section of circuit having constant values of r, L, g, and C, can be integrated by an expression consisting of four terms, two main waves and their two return waves. One of the waves dies out at a greater, the other at a slower rate than corresponds to the energy dissipation in the circuit, and therefore the former transfers energy to the latter, thus representing the energy transfer along the circuit, as occurring in traveling waves, a-c. transmission etc. These two waves coincide, and the energy transfer coefficient becomes zero, in the stationary oscillation of a uniform circuit; they do not coincide, however, in the stationary oscillation of a compound circuit, but energy transfer occurs from sections of lower energy dissipation, to sections of higher energy dissipation.

In the first part of the present paper, a classification of the different types of electric current is made from the general equation of the electric circuit, and in the second part, various forms of the equations of the general impulse currents are derived.

Two methods of studying engineering phenomena exist, which may be denoted respectively as the *synthetic* method and the *analytic* method.

The synthetic method starts with the study of special cases, and by correlation of the special cases, by generalization and classification progresses from special to general, and thus finally to the complete structure of the engineering science.

The analytic method starts from the general (differential) equation of the science based on the fundamental underlying laws, and by substituting all the possible values of the constants and the terminal conditions, thereby derives the different classes of the phenomena, thus progressing from the most general to the special.

As engineering is based on experience, and experiment necessarily deals with special cases, the synthetic method is the first in the development of engineering, and the analytic method, requiring the knowledge of the fundamental laws, can be attempted only later.

However, the synthetic method can never give assurance of the completeness of our knowledge, for entire classes of phenomena may be omitted, if it happens that they have never been empirically observed or recognized. Inversely, the analytic method gives the complete structure, but only so far as it is based on the fundamental laws represented by

the general equation, and thus may not be comprehensive, since any phenomenon which does not obey these laws, would not be included.

Thus the two methods are supplementary, the analytic method checking the completeness of the synthetic, and the synthetic checking the comprehensiveness of the analytic.

The theory of electrical engineering, relating to direct currents, alternating currents, exponential discharges, oscillating currents and other transients, was developed synthetically; and the purpose of the first part of the present paper is, by the analytic method, to derive all possible types of currents by substituting all possible values of constants and of terminal conditions, and thereby check, whether any class of current of industrial importance has escaped recognition. This appears probable, as the observed transmission line phenomena do not entirely agree with the characteristics of the currents by which they are usually explained.

During the development of high-voltage long-distance transmission, phenomena were observed during disturbances in the transmission lines or underground cables, which could not be explained by the normal voltage supplied by the generating machinery. The first attempt at explanation was made in the study of the "natural period" of the circuit, the abnormal voltages resulting from the free oscillation of the line as a quarter wave (or half wave or full wave), and its higher harmonics. In a few instances this agreed fairly well with the facts, thus pointing to quarter-wave oscillations as possible line disturbances. Usually, however, it did not agree for a quarter wave oscillation would be felt over the entire circuit, whereas experience showed most line disturbances were more local in character, that is, very severe at some places, but rapidly decreasing with the distance. It further showed, as characteristic, the piling up of voltage locally, especially at inductive parts of the circuit, such as transformer end turns, inductances, current transformers etc. This led to the explanation of the disturbance as due to high frequency High-frequency travelling waves would give local abnormal voltage, and rapid attenuation with the distance from the origin, and therefore would satisfactorily explain the most frequent line disturbances, except in one feature, namely, that such high-frequency oscillating currents should give pronounced resonance effects. Such resonance effects, leading to the formation of stationary oscillations of destructive value, have been observed and experimentally reproduced in recent years, in the high-potential windings of high-voltage power transformers, usually of frequencies between 10,000 and 100,000 cycles, and their existence has therefore been proved. However, in most cases of transmission line disturbances, resonance phenomena are remarkably weak or entirely absent, and it therefore appears that many transmission line disturbances are impulsive rather than oscillatory, which has led to the question of the existence, the characteristics and the equations of impulse currents.

In a circuit with localized capacity, inductance and resistance, the current is either oscillatory or impulsive, depending on the circuit constants, and more particularly the relation of the resistance to the inductance and capacity. In a circuit with distributed constants however, there is no critical value of constants, that divides the oscillatory and the impulsive phenomena, but, as was shown in the paper of 1908, with the same circuit constants, the phenomena may be oscillatory or they may be impulsive, depending on the terminal conditions, that is, on the cause of the phenomena. Thus oscillating currents as well as impulse currents may exist in the same circuit, although experience seems to show, that at least in long distance transmission lines the latter are rather the more frequent.

To get their relation to the other and better known classes of current, was the purpose of the first part of the present paper.

1. Terminal conditions. The foremost terminal condition is the length l of the circuit. This may be either zero, or finite, or infinite. Substituting $l = 0$ gives the equation of circuits with massed constants: the usual a-c. or d-c. circuits of our systems and apparatus, etc. l = finite gives the equation of circuits with distributed constants and $l = \infty$ gives the case where the circuit is so long, that the disturbance has decreased to a negligible value before reaching the end of the circuit, and thus the reflected disturbance is inappreciable.

2. Constants. The general integral equation of the electric circuit appears as an exponential function, with the time and the distance in the exponent. It thus has a coefficient of the time exponent, b, and a coefficient of the distance exponent, a. a and b are related by a quadratic equation, thus only one is independent, b has been chosen as the independent coefficient. b is a general (or complex imaginary) number, and the two main special cases thus are, (a) where the real term of b is zero, (b) where the imaginary term is zero. (a) gives the alternating currents. (b) gives a non-periodic class of transient currents, which may be called the *impulse currents*. The impulse currents thus appear as a class of currents, as general as, and coordinate with the alternating currents, the latter representing the useful currents of our transmission systems, the impulse currents the foremost type of harmful currents.

The second part of the present paper contains a further classification of the impulse currents, by their distribution along the circuit, as non-periodic and periodic in space, and a derivation of various forms of the equations of the two classes of impulse currents.

Physically, impulse currents, by the steepness of their wave front, give the local piling up of voltage, characteristic of most line disturbances, but as non-periodic currents, they could give resonance phenomena only by multiple reflection, and thus resonance phenomena with impulse currents would be little pronounced or absent.

It appears, therefore, that the most frequent disturbances of our transmission systems show the characteristics of the impulse currents rather than those of oscillating currents, and the study of impulse currents becomes of far greater importance than heretofore assumed.

Thus, the analytic study led to the recognition of the impulse currents as a class of currents, which, while not unknown before, but repeatedly mentioned and discussed, apparently has not sufficiently been realized in respect to its industrial importance.

The reverse operation would now be of interest: to check by the synthetic method, the completeness of the analytic structure, that is, to see to what extent existing or at least industrially important classes of currents are not contained within the scope of the general equation based on constancy of r, L, g and C.

Phenomena are known, which are outside of this equation. Such phenomena are the cumulative oscillations, such as are produced under certain conditions by an arc (not the phenomena of the so-called 'arcing ground;' these are recurrent oscillating discharges), the surging of synchronous machines, the phenomena in circuits operating above corona voltage, etc.

Thus the general equation of the electric circuit, which is the starting point of the present paper and the previous paper, is not all comprehensive, but a still more general analytical investigation is desirable, in which r, L, g and C are not constant, but depend on $\frac{di}{dt}$ and $\frac{de}{dt}$ or an integrated value thereof, as the frequency, etc. Our knowledge of these phenomena is not yet sufficient to attempt an analytic treatment, but more knowledge will have to be acquired by the synthetic method of investigating special classes of phenomena, in a way similar to that attempted with the surging of synchronous machines in the paper on "Instability of Electric Circuits" read before the Chicago Section in 1912.

M. I. Pupin: If I understand Dr. Steinmetz, the object of his paper is to call your attention to a distinct class of electric currents, a class of electric currents which he calls impulse currents and which, he says, has not received as much attention as the direct current and the alternating current. When I saw the notice of the paper and observed the title "Outline of Theory of Impulse Currents," it attracted me very much, because I have always been interested in impulse currents. To me the direct current and the alternating current were simply cases of the more general impulse current.

When Dr. Steinmetz says that equations (4) and (5) "must represent every existing electric circuit, and every circuit which can be imagined, from the lightning discharge to the house bell, and from the a-c. transmission line to the telephone

circuit, with the only limitation, that r, g, L, C are constant within the range of the currents and voltage considered," he should not be misunderstood in his statement, and I believe that he might be misunderstood. I wish to warn you not to misunderstand that statement, because if you do, you might think that after you read this article you need not read anything else on this subject, so, therefore, I want to warn you against that.

Here Dr. Steinmetz considers the general problem on a long line having distributed inductance, resistance and capacity, and he gives you that, starting from a differential equation. What do we mean by differential equations in electricity? We mean simply this—an equation expressing the various relations between the reactions in a conductor. For instance, take the first equation Dr. Steinmetz gives, which looks so mathematical—as a matter of fact it is nothing more nor less than the expression that in any element of conductor the sum of the electrical actions is equal to the sum of the electrical reactions. That is what he says, and that is Newton's third law of motion, that the sum of action is equal to the sum of reactions in every system of bodies.

Dr. Steinmetz says—Suppose there is that relation between these various electrical reactions and various electrical actions, then the following must be the relation between the current and e.m.f. in any part of the circuit. That is what is called the integral of it. From the equation of reactions you get an expression of the current and the e.m.f., and that is called the integral. That is true for any point of the wire which has certain constants.

Now, when you come to another point of the wire where other constants are, then you have to get another expression for the currents, and since you have an infinite number of points, you may have an infinite number of different expressions for the current, and it is necessary to add these different currents and make them conform to the so-called boundary conditions. As soon as you pass from one element of the wire with certain constants, to another element of the wire with another set of constants, you have to pass through that boundary.

The most difficult thing in mathematical analyses of electrical phenomena is that question of the boundary conditions. So that when Dr. Steinmetz says "These equations must represent every existing electric circuit," he does not mean to say that he has given you a complete solution—he means to say that he has given you a complete solution for any part of the electric circuit, but if you want to have a complete solution, good for any part and for the complete circuit, you have to take this part, and this part, and this part and build it up. That explains the point I had in mind.

It is true that there are problems in electrical engineering which have not been discussed at all, and Dr. Steinmetz has

referred to one of those problems which has interested me for years, the problem of the oscillating arc. It may be that in some oscillating arcs the oscillation is due to the variable resistance. It may be. But the electrical oscillation that takes place in a vacuum tube, such as the pliotron tube, is not due to variable resistance, but is due to something else. That is to say, the oscillating arc acts in a very similar manner to the oscillations produced by an induction motor when you drive it beyond synchronism. Take a single-phase induction motor, drive it beyond synchronism, and provide it with a suitable capacity, and you can get oscillations exactly the same as you do in an oscillating wire in the pliotron tube—there is no variable resistance, there is no variable capacity, there is no variable inductance, the only thing that is variable is the mutual inductance between the primary and secondary circuit.

Dr. Steinmetz to my knowledge has not attempted yet to proceed analytically and pursue this elusive induction motor to see what it will do under certain conditions, but undoubtedly he will, and when he does he will find that an induction motor, whether it is single-phase or polyphase, when supplied with proper capacity and constructed suitably can generate these oscillations in just the same way as the pliotron tube or the oscillating arc. Moreover, if he does not take the proper precaution, the oscillations stored in an induction motor of that kind will be oscillations, not with a negative exponent, but with a positive exponent; that is to say, the oscillations will go on increasing indefinitely until his machine is smashed. The machine has to obey the integral of that differential equation, that is to say, the machine has to obey the law of the electrical reactions. The mechanical power that drives the motor acts, the motor reacts, and the result of that action and reaction is continually piling up energy which appears as magnetic energy, and when the current is big enough, of course, your machine will be either smashed, or the pole pieces will be crushed on to the armature and the machine will come to a standstill.

Harold Pender: Dr. Steinmetz has given us an interesting mathematical discussion of an important class of electric phenomena. It is not difficult to see the physical meaning of the mathematical symbols used in the differential equations given in the paper, but this is not true of many of the symbols appearing in the integral equations. For example, on the last page of the paper there are certain constants enumerated, namely, D_1, D_2, D_3, D_4. What are they? In mathematical language they are called integration constants, and physically they have a definite relation to the physical conditions intially imposed on the circuit, *i.e.*, they depend upon the voltage and current initially established at each point of the circuit. But how may these constants be evaluated in terms of these initial conditions? I hope that Dr. Steinmetz will give us at some future

time a discussion not only of the *qualitative* meaning of these constants, which is not difficult to see, but also their *quantitative* values for various initial conditions which may occur in practise.

The differential equation (**3**) in this paper is one that contains, as Dr. Steinmetz has said, a complete solution of single-circuit lines. By a single-circuit line I mean a circuit which does not contain mutual inductance. If there is mutual inductance a second equation is necessary, and the evaluation of the exponents in the various integral relations requires the solution of a cubic equation instead of a quadratic. When there is mutual inductance between the given circuit and more than one other circuit, the evaluation of the exponents requires the solution of an equation of still higher degree. I give this merely to emphasize the fact that the relations given in the paper apply only to a single circuit which is not influenced by any neighboring circuit, a condition which seldom obtains in any transmission system.

Hans Lippelt: The paper, after introducing equations (**1**) and (**2**), puts forward the following statement:

"These equations must represent every existing electric

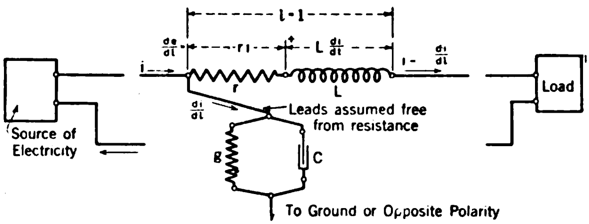


FIG. 1

circuit, and every circuit which can be imagined, from the lightning discharge to the house bell, and from the a-c. transmission line to the telephone circuit, with the only limitation, that r, g, L, C are constant within the range of the currents and voltages considered."

By a peculiar coincidence, it occurred to me that these equations might not include all cases which are situated between the limits given in that statement. As a matter of fact, Dr. Steinmetz in concluding the presentation of the paper tonight mentioned several cases which are not included in these equations. He limited himself, however, again by saying that the cited cases involve variations of the "constants."

To me it seems that there is still another possibility of an electric circuit, which is not covered by equations (**1**) and (**2**). The circuit I have in mind contains capacity in series connection.

Fig. 1 shows in a general way an elementary circuit to which Dr. Steinmetz's equations (**1**) and (**2**) have reference. The figure will be readily understood by observing the notations used

in the paper. The whole circuit is composed of a series of such elementary circuits.

If we have a capacity C_1 in series with the circuit, the latter may be represented as shown in Fig. 2. It is not feasible, however, to assume capacity in each elementary circuit, because the capacity of the total circuit would then be so small that no current at all could flow. The new fundamental equation should, therefore, not refer to the change of voltage per unit length of line $\left(\frac{de}{dl}\right)$, but to a voltage drop in a circuit with massed constants. The length of circuit as such does then not enter into the computation.

If e, the consumed voltage, and the other quantities r_1, r_2, L_1, L_2, C_1, C_2, g, refer to the circuit as per Fig. 2, we have

$$e = r_1 i_1 + L_1 \frac{di_1}{dt} + \frac{1}{C_1} \int i_1 \, dt \qquad (1)$$

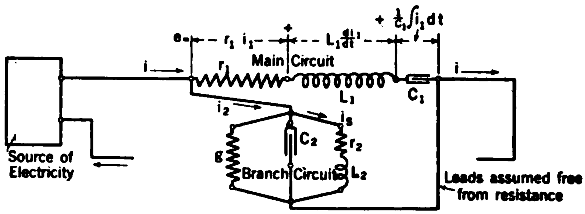


FIG. 2

Similarly, the current diverted from main circuit is, allowing also for self-induction L_2 combined with resistance r_2,

$$i_2 = ge + C_2 \frac{de}{dt} + i_k \times \epsilon^{-\frac{r_2}{L_2}t} + \frac{\epsilon^{-\frac{r_2}{L_2}t}}{r_2} \int e \, d\, \epsilon^{+\frac{r_2}{L_2}t} \qquad (2)$$

wherein i_k is defined by the following:

for $t = 0$
$$\begin{cases} i_s = i_0 \\ e = e_0 \end{cases}$$

$$i_k = i_0 - \frac{e_0}{r_2} + \frac{1}{r_2} \int_{\substack{t=0 \\ \text{const.}=0}} \epsilon^{+\frac{r_2}{L_2}t} \, de$$

finally

$$i = i_1 + i_2 \qquad (3)$$

To solve equations (**1**) and (**2**) requires the knowledge of e as a function of the time, and in this respect these equations differ materially from equations (**1**) and (**2**) of the paper. The latter refer to gradients of quantities $\left(\frac{de}{dl} \text{ and } \frac{di}{dl}\right)$, which are independent of actual values of e and i. Equations (**1**) and (**2**) refer to the quantities e and i directly, of which e is equal to the impressed voltage, which governs the whole process, viz., the vector sum of all secondary e.m.fs. must equal e. In the case of Fig. 1, forming only a small part of a large circuit, this partial circuit may draw stored power from adjacent circuits, involving an adjustment of its terminal voltage, and therefore equations (**1**) and (**2**) of the paper must leave this possibility open, which they do.

A partial, or rather advanced solution of equation (**1**) is given in equation (**4**).

$$i_1 = \frac{\epsilon^{\lambda_1 t}}{L_1(\lambda_1 - \lambda_2)} \left\{ \int \epsilon^{-\lambda_1 t}\, de + K_1 \right\} - \frac{\epsilon^{\lambda_2 t}}{L_1(\lambda_1 - \lambda_2)} \left\{ \epsilon^{-\lambda_2 t}\, de + K_2 \right\} \qquad (4)$$

with

$$\lambda_1 = -\frac{r_1}{2L_1} + \sqrt{\frac{r_1^2}{4L_1^2} - \frac{1}{C_1 L_1}}$$

$$\lambda_2 = -\frac{r_1}{2L_1} - \sqrt{\frac{r_1^2}{4L_1^2} - \frac{1}{C_1 L_1}}$$

K_1 and K_2 = integrating constants.

The last two terms on the right-hand side of equation (**2**) represent the current flowing through the branch loaded with inductance L_2 and resistance r_2, Fig. 2. These terms have been found by treating this branch separately.

To complete the solution of equation (**2**) requires only the substitution of the supposedly known value of e (as a function of time) and carrying out a simple mathematical process.

An application of a circuit with capacity is found in high-voltage d-c. machines, having armature windings of the open coil type. Such machines work entirely with impulse currents and it appears that circuits as per Fig. 2, or similar, will meet the requirements for sparkless commutation of current in the windings.

A. E. Kennelly (by letter): The great advantages of the analytical method set forth in Dr. Steinmetz's valuable paper are:

(1) The integral or primitive equations for all voltage and current waves over conductors are reduced to their simplest fundamental elements.

(2) These equations (**4**) and (**5**) of the paper permit of a new classification of all such voltage and current waves.

When b contains a real component, the paper shows that the wave to which it pertains must speedily disappear. Only when b has no real component can the wave to which it pertains belong to a permanent regime.

There are three cases involving real components of b; namely,

b complex, representing oscillatory transients (1)

b real $\begin{cases} \text{with } a \text{ real, representing non-oscillatory transients} & (2) \\ \text{with } a \text{ imaginary, representing non-oscillatory transients.} & (3) \end{cases}$

The paper distinguishes the two last types by the terms " non-periodic " and " periodic " impulses respectively. But these terms seem to be unsuitable because they suggest recurrence in time; whereas the property in question is a recurrence in distance or space. Would it not therefore be more appropriate to coin the terms " *non-spacic* " and " *spacic* " for this differentiation?

In any case, although the oscillatory and non-oscillatory transients should clearly be distinguished and placed in separate categories, it seems doubtful whether there is enough distinction between the two classes (2) and (3) of the non-oscillatory transients to make their separation important. The paper shows that the only essential difference between these two types is that where a circular distance-angle occurs with the one, a hyperbolic distance-angle occurs correspondingly with the other. Thus both are included in the same generalized trigonometric relations and it remains to be shown whether the differences between them are otherwise great enough to call for separate discussion.

It is perhaps going too far to say that all impulses with real b exponential time-factors are harmful; although the generalization may at present be applied to light and power circuits. In some signaling circuits, as in some submarine cable circuits, such impulses discharging back to ground at the sending end are usefully employed in certain signaling systems.

Charles P. Steinmetz: In regard to the general equation, which I gave in my paper eight years ago, naturally I did not mean that this equation is a final solution of every phenomenon; if I did, I would not have had any reason to write this paper. What I mean to say is that from this equation can be derived the equations of any circuit which fulfills the condition that every one of these four constants r, g, L and C is constant. Where one is variable, whether resistance, or inductance, or the capacity

or conductance, then this general equation does not apply. I mentioned, as an illustration, a couple of circuits where the constants are variable. The transmission line, when operated above corona voltage, also gives a periodically variable conductance.

I referred to the oscillating arc. There I referred to the variable resistance. In the arc it is really a variable effective resistance, as I may call it, defining, as I have done here, resistance as the coefficient of energy dissipation proportionate to the current. The induction machine driven above synchronism also produces oscillations. These oscillations produced by the induction machine when driven above synchronism were discussed in my paper on "Induction Motors" 19 years ago, and their characteris-curves calculated. In the chapter on "Induction Generator" in "Alternating Current Phenomena," a full discussion is found on the conditions under which an induction machine above synchronism excites, of the maximum voltage and current values to which it may build up, and its dependency on the constants of the external circuit. It may be interesting to note that two such induction generators of 10,000 kw. each, have been in operation for years in the Interborough Rapid Transit station in New York City, as generators producing power.

These impulse currents are a special class of transients. Inasmuch as they are a sub-class of the general transient, they are included in the general equation of my previous paper, but they were not specifically treated.

They apply to a circuit, or a section of the circuit, of uniform constants, but the case which Prof. Pupin discussed, where the circuit constants change, is treated in general in my previous paper under the term "Complex Circuits." It is more particularly treated in that section in my book on "Transient Phenomena," which discusses the transition points between different circuit sections of different constants, as lines, transformers, etc. It is very interesting to note the effect on such a circuit of the transients existing; there is an energy exchange between the different circuit sections, the energy being dissipated in some sections at a rate higher than the average, and in other sections at a rate lower than the average,—there is energy transferred, taken from one section and delivered at another section.

With regard to mutally inductive circuits, even these may be considered under the general equation, by suitable terminal conditions, and effective values of r, g, L, C.

I may say that the circuit as described by Mr. Lippelt is in industrial existence. It is the circuit of the multi-gap lightning arrester.

DISCUSSION ON "THE MUNICIPALLY-OPERATED ELECTRICAL UTILITIES OF WESTERN CANADA" (CHRISTIE), NEW YORK, FEB. 8, 1916. (SEE PROCEEDINGS FOR FEBRUARY 1916.)

(Subject to final revision for the Transactions.)

Philander Betts: I think of all those who are opposed to municipal ownership, those that know most about it are the engineers and operators, etc., of utilities. Among those who favor municipal ownership and operation, I think we will find only a small number of engineers. The others are economists, publicists, politicians, most of whom are honest, but the list includes demagogues and others whose arguments are based on personal benefit.

In the observation of the operation of utilities in the State of New Jersey during the past five years, and during the past three years more particularly, since the Commission has prescribed classification of accounts and has called for annual reports from municipally-operated utilities, there has been an opportunity to observe the operations of these utilities, and what stands out most markedly is the chaotic way in which they are operated and managed. The condition in Western Canada appears to be quite different, and brings out some things that I think we have all got to take account of.

I think the paper sounds a word of warning, in a way, and I want to point out what that is. In the first place, municipal financing is based on a theory different from the theories on which our ordinarily operated public utilities are financed. The publicly owned utility or project of any kind is financed on the theory that it will suffice for this generation or for the life of the project, and that a scheme of financing must be worked out so that any bonds issued to pay for that project must in some way be taken up by the time that project is worn out, in this way leaving the future generation free to finance its own projects and determine for itself whether it will renew them. This applies to projects other than utilities, and includes roads, school houses and other public matters.

In regard to public utilities which are privately owned, we are working on a theory that these things go on forever, perhaps not as they are at present constructed, but in some form, and our financial schemes are based on the idea that they will go on forever, that they must be maintained and replaced as they become worn out, and that the capitalization needed to construct them continues and is not entirely retired at any time.

This latter method of financing, if all other things were equal, would really mean cheaper rates, if the capitalization is not retired. That is a mathematical problem, capable of demonstration with a little trouble, but not a matter, I think, which is worth while going into now.

In order to know definitely whether municipally-operated utilities are any better than privately-owned utilities we must have proper methods of financing, proper methods of recording the various transactions involved in the construction of the plants

and of recording the transactions involved in the operation of these plants, and the accounting systems must be imposed by some power superior to the municipal authorities. In New Jersey our greatest difficulty has been to place the responsibility.

Last year twelve of the municipalities in New Jersey operating water departments were summoned by the Commission to explain why they had not furnished a full report of the operations for the preceding year. In each case the Mayor or the Clerk of the Council, or some official, tried to throw the responsibility on some one else, and it developed that almost all municipal operations are conducted on what to a business man is an inexcusably chaotic basis. Receipts, revenues from the operation of the municipal utility, are considered and handled like any other municipal revenue. They are taken up, handled and carried along in the same accounts with taxes, with license fees, and with other revenues. The costs of operating a municipal utility, on the other hand, usually come out of the proceeds from taxes.

Without a proper system of accounting no one knows whether the system is operating successfully or not, from a financial standpoint, and to my mind that is clearly improper. There are a few cases that stand out in considerable contrast, in which the utilities are operated as a business proposition, in which the revenues, expenses, and all the accounts are handled through one department in such a way as to show whether the project operates at a gain or a loss.

In making a proper comparison, however, Prof. Christie has called attention to the matter of taxation. To show how important it is that all municipal utilities should pay their taxes just like any other utility, I want to call attention to a condition in one of the counties in New Jersey, consisting of about twelve municipalities. Ten of these municipalities own their own water departments and two of these municipalities are served with water by private companies. In the system of taxation in force in New Jersey a part of the tax money furnished by the municipalities goes to the county to support the operations of the county and, therefore, a tax collected in one municipality is of benefit, in a way, to all of the municipalities within that county. If the water companies in these two out of the twelve municipalities pay their full share of taxes a large portion of that tax is expended for improvements in the other ten municipalities.

That condition is recognized by many of the municipalities in New Jersey, and has led to a system of trading, by which the municipalities have said, or a particular municipality has said, to the water company—" we don't want you to pay taxes and in turn we will not pay for the municipal water service that we get for our City Hall and School Buildings and Fire Houses, and in many cases for the fire hydrants. We will just exchange credit for these things, and we recognize that we as a municipality, and our citizens within our municipality will be better off, we will keep within our municipality the full amount of money that would be paid by that utility in the form of taxes."

Is that a proper state of affairs? I think not, and I think that shows the necessity for every utility to pay its own taxes, whether it is municipally operated or not, provided any utility is to pay taxes, and it appears to be a well established thing that all property is to be taxed as we now understand these things.

There is another feature which is very important in the operation of a municipal utility. In a few cases in this country—Anderson, Indiana, is one—the service of the utility is paid for at regular rates. Every bit of service furnished by the utility, service for the lighting of the school houses, of the police stations, and other municipal buildings should be paid for in accordance with the regular rate. Street lighting service should be paid for, taxes should be levied, actually, for that specific purpose, and credited to the utility, just as they would be if that utility was operated by a private corporation.

A municipally-operated utility ought not to confine itself, if it is to do its proper duty to the public, solely to any matter of street lighting. It ought to be treated like any other utility, considered as a natural monopoly, and not only be allowed to, but required to furnish every class of service needed in that municipality. It ought to do the lighting, other than street lighting, provide all the necessary industrial power, and all current required in the municipality for any ordinary purpose.

Now, let us consider this question: If every utility was treated exactly the same way, financed in a proper way, kept its operating accounts in a way to show the real result, and if there was an equal amount of efficiency displayed in the financing, construction and operation, then would there be an advantage to the municipality that owned its own utility? There might be in this one way—in the regulation of rates we are often confronted with claims for value which have no basis in connection with the investment. The investment itself might be made up or considered as of two parts, actual investment in the physical property and everything that goes with that, and the investment, just as much an element of cost as anything else, that comes from the lack of earnings in the early years, lack of profits, and the unearned depreciation which must not be forgotten.

Instead of setting up a claim for a value as a going concern, which is the value that ought to be taken into account in a case where one purchases a property as a going concern, or where property is sold,—in claiming a value of that kind, I think we get away from the proper basis, and that is the investment;—a just consideration of the investment will take into account not an element known as going concern but an element that may be about the same, mathematically. It may be far in excess of any so-called going concern value or it may be less, and that is "cost of establishing the business." That includes this lack of earnings in the early years, lack of profits as time goes on, and this unearned depreciation due to the gradual and growing obsolescence of plants and the necessity for replacing them before a reserve has been accumulated to provide for that purpose.

If the claims set up by the company extends that far and no further, then there can be no advantage whatever that can accrue from municipal ownership, provided that in connection with ownership by municipalities the financing and accounting and all operating conditions shall be carried on in exactly the same way that must be done by any efficient business organization carrying on the same class of work.

Henry G. Stott: The fundamental point, it seems to me is this.—Is there any difference between a municipally owned plant and a privately owned plant? Either a municipality or a private individual can buy efficient apparatus, one can construct as efficient a plant as the other. The next question is—What are the objects to be gained under the two classes? In one case, theoretically, the municipal ownership plant is constructed to give service at cost. In the other case, of the privately owned plant, or incorporated plant, admittedly the object is not only to give service, but to make a profit. Under these two plans it would look as if the municipally owned plant ought to give the cheapest service, other things being equal, but actually what do we find? We find this, that in the municipally owned plant as a rule—I am talking about conditions in this country—the plant becomes the prey of politicians.

In one case there is a basis of trading political preferment without any desire to earn dividends. In the other case there is an actual and avowed desire for gain. There is no secret about it. The privately owned corporation exists to make money for its stockholders, and therefore must be operated efficiently. These are the two fundamental differences.

If we can get away in the municipally owned plant from the idea that every alderman or councilman or politician has a right to send men around for this, that and the other job in connection with the municipally owned plant, and if there are no jobs open for them, the jobs must be made, with the resulting demoralization of the staff, then the municipally owned plant will be equally efficient and equally well operated as the private plant—there is no doubt about that—but we have no symptoms of that change in method at the present time.

The biggest problem in the electrical industry today in connection with the business of supplying power, is the question of obsolescence. In the case of the average plant today the greater part of the machinery becomes obsolete in from ten to fifteen years; very little of it lasts fifteen years, the average is about twelve years. I know of one case where a piece of apparatus which cost a quarter of a million dollars twelve years ago was scrapped recently and sold for $8000. We should establish an obsolescence fund. It is a proper charge against the cost of making power, because we know as certainly as it is possible to know by the history of the past that in the future there will be further developments, so that during the course of every decade or a little more, we must completely revolutionize our plant. This is a difficult thing to have recognized in any

municipality today, the fact that a charge for obsolescence is a proper one to make.

If we could, as Mr. Christie suggests, have one man put fully in charge of a plant and make him absolutely responsible for the operation and for the financing of it, and have every one connected with the plant follow his instructions without outside interference, then I see no reason why the municipally operated plant should not be operated equally advantageously with the ordinary privately owned plant. But they cannot be upon any equality, until we get rid of the idea in this country that the municipally operated plant is the means of passing around favors for the politicians, and until we put it on the basis of actually earning a revenue for the stockholders who are the tax payers of that city.

R. P. Bolton: Mr. Christie has almost wholly disregarded an essential element which is rarely offered and generally almost impossible to secure in regard to municipal undertakings. This is not only the rate or cost, but the extent of the contributions made to the income of municipal utilities by other branches of the municipality. The paper contains but one slight reference to this subject.

My investigations in Winnipeg and a number of cities in Ontario, have convinced me that municipal officials generally guarantee either an excessive use of electricity or charge high rates for energy supplied for municipal purposes. In fact I have found instances where the amount guaranteed has deliberately been made sufficient to secure the appearance of a surplus upon annual operation.

I can offer a particularly definite illustration of this in the operation of the municipal hydroelectric system in the City of Toronto, from the report of which for the year 1914, I take the following figures:

Out of a total income of **$1,501,291**, no less than **$562,353** was derived from the payments made for the lighting of streets, of public buildings, and for power used in municipal water supply, pumping, etc. The total cost of the electric energy supplied, both for municipal and for all commercial purposes was **$324,236** while the charges paid for street lighting by the municipality to the electric system amount to **$364,214**. For municipal power purposes, the sum of **$157,700** was paid. I learned that the cost of electrical operation of the pumping service was in excess of that for steam operation, and that the chief engineer of the water department resigned his position several years ago following the disregard of his protest against the change of system made necessary by the attempt to supply electric service to the municipal pumping system.

So far as street lighting is concerned, the cost for **1914** may be compared with the cost prior to the establishment of the municipal system, when the city was lighted by the Toronto Electric Company at a total cost of **$135,000**. Thus, in about five years of operation, the cost of street lighting has been nearly trebled.

The result of these excessive contributions by the municipality was, for the year 1914, to bring about a surplus amounting to about 4½ per cent of the total income which, as is evident from the foregoing figures, is not real but merely apparent.

The total energy used for the year 1914 of this municipal system was as follows:

For residential and commercial lighting, kw-hr... 13,752,500
For commercial power, kw-hr.................. 20,724,800
For municipal purposes, light and power, kw-hr... 50,115,000

It may be conceded at once that the large quantity of energy absorbed for municipal purposes warrants a low rate per unit, but it is the total contribution which brings about the effect upon the municipal accounting.

In making investigations in Winnipeg, I found that very similar conditions obtained there. I was informed at the time of my last visit that the city pumping department was being charged a higher rate for energy than was a commercial undertaking in the immediate vicinity, although the city pumping was an off-peak load and the commercial operation a twenty-four hour load.

The situation in Winnipeg has not been quite fairly reported to Mr. Christie, judging by his description of it. The private corporation to which he refers had been in operation since the year 1892, and, during the greater part of its existence no dividend had been earned upon the capital invested. At the time of the commencement of the agitation for a municipal electric system upwards of $4,000,000 had been invested by this company, upon which only 5 per cent was earned, while the arrears of unearned dividend at that time amounted to nearly $300,000. The agitation was not directed by any necessity for a supply of very cheap power, since power was at that time available for industries at rates as low as they are today. The company had also voluntarily reduced its rates for domestic service and the maximum charge for the minimum service was the ten-cent rate.

In point of fact, the agitation for a flat three-cent rate for domestic service in which the city has become involved was started by cetain ill-informed persons for political purposes. This unfortunate local agitation has resulted in a total investment of nearly $7,500,000 and the bonded indebtedness of the city has been increased 33 per cent by the process. As in the case of other cities described by Mr. Christie, lying further west, the result has been disastrous to the credit of the communities, and in my judgment, the present unfortunate situation in western Canada is largely attributable to this unnecessary class of investment. The same remark applies in a degree, to cities in Ontario.

The extravagant investments of these cities and particularly of Winnipeg, are due to an ill-informed faith in hydroelectric generation of energy, involving expense far in excess of that of first class steam power plants, and presenting very often great

difficulties in the way of any future radical change or enlargement. This point is well illustrated by conditions in Winnipeg, the cost of its plant per kilowatt of installed capacity being $132. A first class steam plant might have been built at $50 per kilowatt of capacity. The fixed charges on the difference of $82 upon the output recorded for the year 1914, amount to 0.37 of a cent per kw-hr. which is equivalent to the cost of coal at the rate of 1.8 pounds per kw-hr. and at the price of $4.00 per short ton. The excess investment amounting to $2,500,000 has, therefore, little or no commercial value.

Moreover the municipal plant in Winnipeg as in other places, is lacking in stability as a result of the liability to failure of all hydroelectric and transmission systems, and is in this respect at a disadvantage when compared with the system established by the private company which has a large steam power plant in the city. From these facts a peculiar situation has arisen. Sundry consumers upon the municipal system are paying for breakdown service on the private system as a reserve, being thus put to double expense.

The State of Manitoba has established a public service commission system, one of the problems of which, as described to me by the Commissioner, was how to deal with the unfair competition established by municipally operated systems like those in Winnipeg. The various municipal systems in the province of Ontario are under the control of the Hydroelectric Power Commission of that province by which a uniform system of accounting has been established recently. In this accounting system depreciation must be provided for. No provision, however, is made for the bringing out of the extent of the contributions of the municipality toward the support of its electrical utility. I have investigated instances in which, in order to make up a prior deficiency, the amount of street lighting in a small town has been doubled in a year.

In view of this feature of Canadian municipal operations, it would seem necessary that all the facts should be known before decision as to their financial failure or success is made. Information in the paper is, as I have said, meagre, but enough is stated to indicate that the process I have described is evidently being followed. Thus, for railway services, prices are apparently charged which vary all the way from $1\frac{1}{2}$ to 2 cents per kw-hr. Arc lamps are charged as high as $65 and $70 per annum. In Calgary, the street lighting is charged at the rate of $24 per 100-watt equivalent. Doubtless further investigation by Mr. Christie would bring out other remarkable illustrations of the methods by which this process is pursued.

My own attitude toward municipally operated utilities is dictated by a desire for fair treatment and full consideration of the right of communities to decide whether they will pledge their own credit to effect certain results or allow other persons to do it for them, at a reasonable price. But I regard it as the first

duty of the engineer to avoid deceiving himself and deceiving others. I have never been able to find that the municipally operated utilities in Canada were free from methods open to criticism as being unequal in effect and unfair in method. Until we can be informed fully upon every important phase of the subject, judgment as to the relative efficiency and financial success of the Western Canadian municipal utilities should be suspended.

Edward J. Cheney: Mr. Christie gives us a good deal of information on what can be done, but the real question is—what *will* be done—in the situation in which we are interested. When our city governments can conduct present operations in an efficient and economical manner, it will be time to say that we can take up the municipal ownership and operation of public utilities on a satisfactory basis. For whatever reason it may be, municipally owned plants in this country do not show as successful operation as Mr. Christie shows for the Canadian ones. There are some notable exceptions, but I think invariably they are due to the fact that some broad minded, public spirited citizens, without compensation, have taken charge and kept the operation out of the hands of selfish interests.

The country which Mr. Christie has studied is new. The very rapid growth of the territory is in itself favorable for successful operation. The citizens appear to be non-political and interested in general business affairs. That atmosphere is not conducive to the development of politicians or their education in the use, for selfish purposes, of publicly owned utilities.

I do not wish to appear pessimistic, but there is some indication in the paper that those conditions may be changing and it is possible that those cities may ultimately reach that unhappy stage of development, with which we are fairly familiar in this country, in which the possibilities of exploiting the public utilities are well understood and fully taken advantage of.

It is suggested that state or provincial regulation could be used to smooth out and correct the irregularities of the municipally owned plant. Now, in this state we have state regulation which theoretically controls such plants, but the trouble is to find the man or the set of men or the organization that you can control. How do you get hold of anybody you can do anything with? I know of one instance in which the electric distribution system in a certain city was in a deplorable condition. It not only rendered good service impossible, but was an actual menace to life. The matter was taken up with the men who had charge of the plant, and these men said—" Well, we would have to go to the Board of Aldermen, and if the Board of Aldermen submitted to the citizens a bond issue, the citizens would not vote for it. We have no money and what can we do about it?" What, as a matter of fact, can be done in such a case? You cannot make men, who have no money, do anything which requires the expenditure of money, and you cannot make an order directing the citizens of a city how to vote.

Clayton H. Sharp: Is it not due to the municipal trading in these cities of western Canada that the ratio of municipal bonded indebtedness to assessed valuation of property is much higher than is allowable, for instance, in any city in the State of New York? It might be interesting to have some statistics as to the ratio of bonded indebtedness to assessed valuation.

Is it not true that municipal trading is somewhat responsible for the fact that the debentures of these cities have to be sold on the market at prices at which they will pay the investor in every case considerably more than five per cent, and often as high as six per cent?

J. G. Glassco: In Prof. Christie's paper under the heading "Debenture Issues and Sinking Fund," second paragraph, this statement is made:

"Winnipeg also maintains only a depreciation fund which provides for the maintenance and replacement of the plant. Hence at the expiration of the life of the bonds (30 years) the plant will still be maintained in first class condition and still in service. The expiring bonds can then be redeemed by a new bond issue."

This is exactly contrary to the facts, as all our financial statements and reports on the plant demonstrate clearly our policy of having maintained an adequate sinking fund.

What our policy really is, in this connection, is to apply standard rates of depreciation on the different integral parts of our plant, the average rate in our case approximating 4 per cent of the total investment. From this reserve are deducted the necessary sinking fund levies, which approximate 1.8 per cent, leaving a balance of approximately 2.2 per cent which is applied as a replacement reserve account. This replacement reserve account, at the present time, exceeds half-a-million dollars and is entirely exclusive of the sinking fund levies, which have now accumulated to the sum of $370,000.00. This money is handled by trustees appointed by the judiciary and is the first obligation that we are compelled to meet after the interest on the bonds. We further have no control whatever of this money once it is handed over to the trustees, who are the financial guardians for all these monies on behalf of our fiscal agents and bond holders.

Arthur Reid: There are one or two points in the Lethbridge plant information that are not quite correct.

Prof. Christie gives the cost of plant in Table IV as $456,370.78 and the rated kw. as 2300. This value is evidently the items "land, bldg., and machinery and tools" in the auditors statement.

This is not altogether correct because $2,000.00 of the tools account would be charged to the distribution cost. Although the auditor's statement does not show an itemized statement of the amount under "land, bldg., and machinery," this amount includes the following which should not be charged to the present electric plant.

Cost of pumping plant and alterations to power house building, to accommodate pumping plant..	$53,138.00
Cost of old plant destroyed by fire.................	48,200.00
	$101,338.00

Actual cost of new plant $456,370.78 − $2,000.00 − $101,338.00 = $353,032.78 ÷ 2,438 kw. = $144.80 per kw.

He has given the rated kw. of plant as 2300 instead of 2438, if you add the capacities as given on the plates on the machines viz: 350, 588 and 1500, you will get the above figure. Lethbridge as well as Saskatoon, had a society started by myself for mutual improvement along technical lines for the departmental employees.

In addition to the reason given by Prof. Christie, for the utility being taxed on the same basis as other industries, we have always put the following reason first—The money borrowed to create the utility is borrowed on the credit of the whole city and therefore the municipality is entitled to some return for this credit.

Regarding the disposal of surplus, since the city of Lethbridge purchased the electric plant, it has always been the policy to cut the rates for electricity to produce a revenue as near the operation costs as possible and what little surplus remains is transferred to general revenue.

The reason for the above is, because the electric light and power consumers are nearly all rate payers, if not directly, then indirectly through landlords, etc.; then, if the rates are high enough to produce a large surplus and this surplus is paid into general revenue and goes to reduce taxation, the electric light and power consumers are being overcharged to help reduce the taxes on all property including that held by parties living in other parts of the world who do not contribute one cent of the electric revenue. Therefore, it appears to me, that the only fair way is for the utility to pay the same rate of taxes as any other industry and keep the electric rates as low as will produce a slight balance on the right side of the books. This is what the city of Lethbridge has endeavored to do. Of course, in following out the above, you lay yourself open to the danger of a falling off in the receipts and are then likely to face a deficit at the end of the year, but I think this should be taken care of by putting surplus that may accrue, into a contingency fund to take care of such an event.

A. G. Christie: Mr. Betts has brought out very clearly some points in financing that deserve attention. He justly insists that the utility itself should bear all costs connected with its financing and operation. Too often the equipment does not last as long as the life of the debentures.

Mr. Scott has emphasized in his discussion one of the most important essentials for success in municipal ownership, viz—one-man control. This, and the spirit of cooperation between citizens and the utilities seem to me to be the real basis for the results shown in the West.

I have had considerable difficulty in impressing on municipal officials the necessity of figuring ample obsolescence allowances, and Mr. Stott's statements in this connection will materially assist in emphasizing my point in regard to the short life of present day machinery.

Mr. Bolton's contribution to the discussion is very timely for by introducing the question of municipal revenue to the utility, he calls our attention to a factor that in times past has been one of the greatest short-comings of public ownership. However, genuine attempts are being made in western cities to overcome these defects by charging for all service on the meter basis. But, as is shown in the paper, several still maintain fixed rates per lamp, and are thus still open to criticism.

In regard to Mr. Bolton's figures from Toronto, I am not intimately familiar with the situation there. However, these hardly seem fair, for he considers only lump sum figures and does not present the cost per unit or the increase in the effectiveness of the lighting system. From 20 years acquaintance with Toronto, I am able to say that it has never been better lighted than at present, and this of course, takes additional power. Furthermore, Mr. Bolton apparently discounts also the rapid growth in population and extent of Toronto from 1909 to 1914.

When one discusses Winnipeg, its situation must be clearly kept in mind. The long haul from the Alberta coal fields made the cost of steam power prohibitive. Hence the people naturally turned to water power which is available in great quantity in the country to the northeast of the city. Whether Winnipeg was warranted in expending so much on its hydroelectric system is a difficult question to discuss, yet the fact remains that the electrical utility is supplying probably the cheapest electrical power in America and is earning a surplus at the same time.

In regard to Mr. Sharp's question about bonded indebtedness, I must admit that I am not familiar with New York state figures, and I do not believe that I have the necessary figures from the cities of Western Canada to make satisfactory comparisons. I believe, however, that the ratio of bonded indebtedness to assessment will be found higher in the West than in New York.

It would puzzle one to get a fair basis for comparison in regard to assessment. Some cities are under single tax. Others have cut assessments since war broke out, while others have very inflated land values on all real estate.

The high rate of interest on Canadian municipal bonds was largely due before the war to considerable doubt among British financiers of the ability of these municipalities to pay for these debentures. They failed to realize the rapid growth of these cities. On the other hand, some cities like Saskatoon started out on too ambitious a scale.

Mr. Glassco's contribution corrects an unintentional error on my part due to a misunderstanding of their system.

DISCUSSION ON "OPERATION ON THE NORFOLK AND WESTERN RAILWAY" (WYNNE), NEW YORK, FEB. 9, 1916. (SEE PROCEEDINGS FOR FEBRUARY 1916.)

(Subject to final revision for the Transactions.)

A. H. Armstrong: The induction motor has one inherent characteristic, constant speed at all loads, that makes it of doubtful application to the haulage of trains over a broken profile. The speed of the motor can be varied only slightly except by changing its number of poles, a matter of doubtful expediency in its practical application to the operation of a train. We have been educated in steam railroading to expect the flexible speed characteristic of the steam engine, that is, slow running on ruling grade and proportional higher speed on the lesser grades and level track. Railroad practise therefore is more or less crystalized about the flexible speed operation of the motive power, and in adapting the induction motor to train haulage we are going against all previous ideas, and the continued operation of the Norfolk & Western Railroad will be watched with considerable interest as throwing light upon the adaptability of the induction motor to main line service.

The author gives little data in regard to the question of change of speed except that certain lighter trains will change from 14 to 28 miles per hour where the ruling grade is favorable. No reference is made to the fact that drag freight trains operate over a broken profile, and the inference is gained that such trains operate at a constant speed even on the considerable stretch of low grade track over which a higher speed would be permissible. With the steam locomotive or the d-c. motor locomotive, the sloping characteristic curve inherent in such motive power automatically provides for a change in speed inversely proportional to the gradient of the track.

Very little is said in the paper about regenerative braking although the induction motor inherently provides this feature. So much interest is attaching to electric braking on the Chicago, Milwaukee & St. Paul installation that I may be justified in commenting upon several operating facts found in connection therewith. The method of handling trains going over the crest of the grade and starting down is a matter calling for a considerable amount of skill. Having little to guide us in this direction I had hoped that the author would have brought out something more of the practise prevailing on the Norfolk & Western.

As the train surmounts the grade and the leading locomotive starts to descend no trouble is experienced in applying the electric brakes and in passing from motoring into braking unless the train is brought to rest and then re-accelerated on down grade. In starting on a down grade it is sometimes difficult to change from motoring into braking without introducing the possiblity of breaking the train in two. One method of minimizing this trouble is to tip the retainers on a certain number of the leading cars of the train so that an application of air will result in bunching the slack on the leading locomotive.

The change from motoring to braking can then be effected without occasioning a surge. It has even been possible to hold back a 3000-ton train on a 2 per cent grade with electric locomotives in different parts of the train both braking electrically. No exact method of handling the train down grade has as yet been established, but the greatest success has attended the use of electric brakes and the energy returned to the line has been approximately 15 per cent of the total average demand of the first engine division electrified on the Chicago, Milwaukee & St. Paul road.

It is, of course, understood that retainers are kept in use only during the initial period of changing from motoring into braking, the air is then allowed to leak out and the train handled in its entirety by the electric brake. The electric brakes will hold back the entire train provided the locomotive weight on drivers will furnish the necessary tractive effort without exceeding a coefficient of adhesion permissible with the condition of the rails. For example, on ore roads where the grade favors the load it is current practise for the locomotive to handle a train down grade which is very much heavier than the same locomotive could haul up grade. This is made possible by the application of air brakes to all cars, and if an attempt is made to hold back the train by electric brakes on the locomotive it would demand such a high tractive effort as to exceed the ability of the locomotive to hold the train back and the wheels would slip. With such trains therefore it is necessary to supplement electric brakes by a certain amount of air brake application or else install locomotive capacity greatly in excess of what would be required to haul the empty cars up the grade on the return trip. The combined use of electric and air brakes introduces some new features which are not as yet reduced to a standard practise, but undoubtedly the constant speed characteristic of the induction motor introduces a handicap where electric braking is supplemented by air brakes, and this is due to the samll latitude which such motors permit in speed variation. The d-c. locomotive is much more readily adapted to the combined use of electric and air brakes, as the speed at which electric brakes can be applied extends over a considerable range and thus fits in better with the combined use of electric and air brakes in cases where the electric locomotive has not sufficient weight on the drivers to hold back the trailing load on down grade. The constant speed characteristic of the induction motor therefore may prove to be a serious handicap not only during the period of motoring over a broken profile but also during the regenerative period down grade where the combined use of electric and air brakes may be enforced.

Some reference has been made to the question of wheel correction, that is, the induction motor being a constant speed motor will operate at a constant rotative speed while the locomotive speed will be proportional to the wheel diameter. When

all wheels are new any two locomotives may be coupled together in the same train and all motors run at the same speed. After the tires have been turned, however, there might be coupled to the same train two locomotives having tires of different diameter, in which case a constant resistance must be interposed in the motor secondary geared to the larger wheel diameter in order that the wheel peripheral speed shall conform to that of the smaller wheel diameter. This constitutes a loss in efficiency which is peculiar only to the split-phase or induction motor type of locomotive and adds to the burden of locomotives of the Norfolk & Western type which already have a very low efficiency due to the losses in transformer, phase converter, gears, jack shaft, side rods, etc. It will be interesting to know the efficiency of these locomotives especially after they have been operated for a sufficient period to call for the turning of tires.

R. E. Hellmund: The regenerative control of the Norfolk and Western locomotives, was found to work much easier and better than had been anticipated. When the heavy train is pulled up the hill and passes the crest, it is only necessary to keep the power on the locomotive in the regular way and the locomotive picks up the regenerative load car by car automatically and the engineer has practically nothing to do. You can stand on the locomotive and watching the ammeters observe the increase in regenerative current as each car bumps up against the car in front of it; there is a succession of these little bumps, and you can practically count the cars as they are picked up by the locomotive. It works very smoothly and without any trouble. In fact, some of the operation which originally it was not contemplated to do by electric braking is now being done in this manner, because it is much easier than the air braking.

In the control of the locomotive, the water rheostat is of some interest, in so far as its control is different from the type of controller commonly used on electric locomotives. We are all accustomed to have a master controller which is worked by notches, to increase the voltage on the motors or change the connections. In this particular locomotive the water in the rheostat is lowered and raised by means of a handle, the operation of which is somewhat similar to the operation of the throttle lever of the steam locomotive, and it seems that the steam engineers find that very convenient and much to their liking.

As to the limiting speeds of the induction motor, which have been considered so much of a disadvantage, we find more and more that this feature can hardly be considered as such. About six or seven years ago when I first saw three-phase motors operating in Italy, I was very much worried about their disadvantages. I was told however, that as an actual fact, the service could be handled better and easier than with steam, and while steam trains were frequently late on the steam lines the electrical trains hardly ever were late; this is because variable

speed locomotives will lose time with overloads, while the three-phase motor always runs at the same speed and there is less chance for losing time.

Then, of course, there is the possibility of losing time in the stations for various reasons, and the argument is that such time cannot be made up by the constant speed locomotives. It is to be considered in this connection that most railway equipments are worked about to their limit nowadays, and whether you have the series characteristic or the constant speed characteristic, you cannot make up time except by shortening the coasting period. This can be done with a three-phase motor as well as with a series characteristic motor. If you want to make up time, the only chance you have in either case is to make it up by keeping the power on longer. For this reason it seems that the slight difference between the two motor characteristics apparently does not grow to be a great disadvantage in actual practise. In Italy they handle passenger traffic to a very large extent with three-phase motors, and they are altogether satisfied with the limited speed characteristic.

Francis H. Shepard: Railroad service on the Norfolk and Western is far from toy railroading. These locomotives weigh 270 tons, and to give you an idea of the amount of power handled, with an ordinary train accelerating on the grade the power runs from 8000 to 9000 kw. per train. On certain accelerations which have been made for demonstration purposes, the power reached 12,000 kw., and on a single locomotive, also for demonstration purposes, on the 28-mile connection, 8000 kw.

In handling a long train, I might say that some twenty years ago I lost my respect for the strength of railroad equipment. Down in the Baltimore and Ohio tunnel we broke trains in two as though they were a string of egg-shells. A train is not an inflexible structure; the least little jerk on the controller may tear the train in portions, and one of the necessities in handling heavy trains, and particularly in getting satisfactory performance with the train, is to have absolute control of the motive power. The more refined control of the train you can get the better off you are.

It is a serious matter for a Mallet pusher to slip at the rear of a train, in that it commonly results in breaking the train into two or three parts. When you break a train in two on these grades with cars with lading which weigh 130 tons each, it is because no draw-bar or draft rigging can stand the surge and shock. For instance, on one occasion on the Norfolk and Western inadvertently the trolleys were lowered on the rear or pusher locomotive; the power was cut off thereby, and the train broke into three parts. These locomotives are, of course, interesting to everyone who sees them and rides on them. This accident happened because the conductor seeing these levers wanted to know their function and whether they were operative, and was told " No, they are all cut out, except on the operating end." That was

the fact, except for the trolley down button. That was the very one he pushed.

The operation of the liquid rheostat has been amazingly successful. There are many operations which take place in handling these heavy trains which do not follow the pictures we ordinarily consider railroad operations are governed by, the speed-time curves of the designing engineers.

It is not uncommon for a train to have stuck brakes, to have an excess tonnage, or to require a slow-down movement, and the facility and capacity of the water rheostats to secure these abnormal operations is, as I have said, amazing. The curvature on the Norfolk and Western is so great that with the long trains it is quite impossible to pass the customary whistle and other signals from the head to the rear of the train. In the operation up the grade, the head engineer gets a " slow " order, the pusher engineer has no knowledge whatever of this, the head engineer shifts his load by inserting resistance, the rear engineer receives immediately a corresponding increment of load, he also in turn shifts, and thus they may drop down to half speed, or less than half speed, and then when the slow order has been satisfied and they wish to accelerate up to full speed again, the head engineer opens up; the rear engineer sees he is opening up, so he does likewise, and the whole operation is carried on without any surge to the train whatever.

The result of this is that extreme facility in operation is secured and a very material decrease in damage to equipment over that inherent to a variable speed locomotive such as one operated by steam.

As to the inflexibility of the induction motor, a few years ago I agreed entirely with Mr. Armstrong's opinion, as expressed this evening, but I must confess that I have changed, and that change in my position has been very largely governed by our operation and analysis, together with contact with railroad men. These motors operate so satisfactorily that the dispatchers and tower men will despatch one of these constant speed trains ahead of a passenger train, definitely figuring on only a minute or two leeway, and know that the train is going to clear. You thus get the capacity out of the railroad because the dispatchers and tower men know that trains will start and clear in a certain number of minutes and that the first-class trains will not be held up. In the case of steam operation, when they give a train a clear track they do not know when it is going to clear.

The operation of the induction motor for regeneration is exceedingly simple, and the ease with which it is operated has resulted in the men using the air brake only when they really have to, that is, to come to a standstill. Even in light train or single locomotive operations it is not unusual for them to regenerate, because it is the simple and easy way of governing the train.

Every one who has ridden on a mountain grade knows that

the dropping of a train down a grade is not at constant speed or anywhere near constant speed. The train hunts in speed up and down the grade, and before you get the last service application to the brakes you are always more or less concerned, and greatly relieved when you know that you have reached the foot of the grade. In swinging over to constant speed regeneration, while going over the summit of the grade, the operation is simply the switching of the levers to secure a little better operating characteristic on the locomotive,—it is not really essential,—and we take down a train of 103 cars, which is a pretty sizable train without touching the air and would not spill a drop of water out of a glass in the caboose.

Swinging into regeneration from start, on a down grade can be accomplished with about the same facility. There was originally some concern as to how we would tip the train over the summit, whether the head engine would not give a terrific surge to the train, but as I say, this is handled with great smoothness.

In taking a train down a mountain grade with this system, you feel as though it were tied; that is, the sensation when you go down with a constant speed locomotive, no running up in speed and no occasion, therefore, for any excess in tractive effort above the holding tractive effort. There is a vast difference between the adhesion required to start a train on a grade and the adhesion required to hold that same train going down. a grade. By that margin this inflexibile characteristic is advantageous.

We are taking 3250-ton trains down a pitch of 2.4 gradient from the head end without touching the air. This exceeds the adhesive limit you would ordinarily assume. This is done regularly, a dozen or twenty times a day. If, for any reason, the rail is bad, you can very readily touch up the train with a light brake application, and take part of the retarding effort with the train brake. I may say that retainers are not used, they have not been found necessary to secure smooth control of the retardation.

If the engineer should for any reason during regeneration handle the train brakes improperly—and, by the way, there is more opportunity to wreck a train by improperly handling the air-brakes than in almost any other way—the constant speed characteristic in the induction motor shows its great advantage, for the speed of the train is absolutely held until the train brakes have full control of the train. The train brakes must positively have control of the train before the locomotive holding that train loses its holding power, and therefore it is a perfectly safe and smooth operation, simply to shut off the controller.

In bringing the train to a stop on the grade, the brake application is always made first, and as soon as the motor ceases holding, the train is under full control by the air with auxiliaries fully charged, there is no chance of running up, and the train is slowed down from its constant speed of fourteen miles an hour.

The men who handle these constant speed motors are delighted with their inflexible speed characteristics and it is noteworthy that on regeneration there has never been a case of slid wheels or train broken in two.

B. A. Behrend: We have discussed the subject of the electrification of trunk lines for the past ten years. The situation seems to be about the same today as it was ten years ago in regard to unanimity of opinion as to the best system available. Mr. Wynne's paper and Mr. Shepard's able discussion of it have demonstrated without doubt that single-phase generation and single-phase distribution to single-phase-three-phase locomotives has been successfully executed on the Norfolk and Western Railway. Mr. Armstrong's discussion has reminded us that high-voltage d-c. distribution to high-voltage d-c. locomotives can be, and also has been, successfully carried out on a large scale. We are further aware that single-phase generation and distribution to single-phase locomotives has worked out successfully on the New Haven Railroad. It remains only to raise the point whether the difficulty of three-phase distribution is such as to make impossible the use of three-phase generation, three-phase distribution, and three-phase locomotives. Unless the use of two trolleys, which three-phase distribution necessitates, is as prohibitive as the railway engineers make us believe, it would not seem permissible to resort to the additional complications of adding on each locomotive a single-phase three-phase synchronous converter. It must always be borne in mind, as has frequently been stated since the advent of the single-phase railway, that the generation of single-phase currents is a very uneconomical process, involving problems of design of single-phase generators which are very difficult of satisfactory solution. It must always be borne in mind that the best single-phase generating plant conceivable, if it were to be utilized for three-phase generation, would, electrically, almost be doubled in capacity merely by the utterance of that magic word three-phase for single-phase. After all, then, perhaps, such great engineering achievements as the electrification of the Norfolk and Western Railway, or the Chicago Milwaukee and St. Paul Railway, must be described as the least unsatisfactory solution of a difficult problem rather than as the most satisfactory solution that can be devised.

W. I. Slichter: Whether we believe in one system or the other, I think that all of the systems have shown that the electrical engineer by one system or another can move the freight and the passenger traffic on big trunk line railways more economically, more reliably and more satisfactorily than the steam locomotive. Each system, as Mr. Behrend has said, accomplishes the result, and whether it is the best system in the end, I believe nobody is able to say any more that any one can say any particular steam railway has the best system.

In this system we have the application of three-phase motors to heavy work. I think we all concede that this heavy

coal-bearing traffic is the best place in which the three-phase motor could be put. The three-phase motor has the great advantage of being able to regenerate power with the simplest and easiest connections. It has the disadvantage that it is a constant speed motor, and that it is very sensitive to changes in voltage. That is one point on which I would like to question the author—what variation in voltage at the locomotive has been experienced in practise, and whether this loss in voltage has been found to be of any great disadvantage. We are aware that the torque of the induction motor decreases as the square of the voltage.

The phase converter is a very interesting piece of apparatus, which meets the railway operator's criticisms of the polyphase motor, in being able to take single-phase currents and convert them to three-phase currents and give the polyphase induction motor the currents it needs. At the same time, it adds one more link in the chain as to reliability and as to drop in voltage. It adds certain increase in weight, and we have then the question—Is it worth while?

This regeneration is of very great value in saving equipment by holding the trains on the curves, but it requires additional care in management. On this road is the traffic sufficiently great so that the regenerated energy from trains going down grade may be taken care of adequately by trains going up grade, or is some regulating device provided, so that in case trains are only going down grade and none going up grade, the excess energy will be absorbed somewhere?

R. E. Hellmund: The previous speaker made reference to the sensitiveness of the induction motor to voltage variations. It is quite true that the torque of the induction motor varies with the square of the voltage, but on the other hand it is not at all difficult with these large motors to design them for torques very much in excess of the rated torque. With the Norfolk and Western locomotives, for instance, I believe the slipping point of the wheels is about, I should say, 200 per cent of the rated load of the motors, while the motors are good for 400 per cent at normal voltage. Thus you can readily see that assuming 20 per cent voltage drop, or even 25 per cent, and a corresponding drop of 40 or 50 per cent in torque, the motor torque will still be in excess of the slipping point of the wheels, in other words, there is always plenty of torque to get started. After the motors are once up to speed, the variation of voltage simply means that the load current will change; it will increase inversely proportionate to the voltage; however, the increased copper losses caused thereby are largely compensated for by decreased core losses, and for that reason it is a matter of fact that the induction motor will run with pretty nearly the same temperature with voltage variations of 10 to 20 per cent. Of course, that depends somewhat on the detail design, but as a rule there is not much difficulty in taking care of the voltage variation.

Charles F. Scott: We have before us certain railway performances. In steam railway operation there is no performance equal to that which has been described here this morning. Trains of over 3000 tons have been run up grades at the rate of 14 miles an hour, train after train, in regular and heavy service. After the long development of steam locomotives, a dozen or so of the electric locomotives are doing the work of something like thirty of the best steam locomotives that could be obtained. The electric train service is something like twice what is possible with steam, *i.e.*, the highest speed and power found practicable in steam operation have been doubled in electrical operation and the capacity of a congested track has been doubled.

In comment, what are some of the questions which are asked? Some inspect the outfit with a sort of microscope and say, "This might be different, or that might be different." One of the gentlemen who took part in the discussion this morning, is artistically pessimistic. He says about the generator—"Why, if it were a three-phase generator, you could get twice as much out of it." Surely, but the generator is a small part of this system. Moreover, is not the generator on the basis of kilowatts output per pound of generator, giving a performance comparable to that of any generator, a dozen years ago?

A question has been raised about two trolley wires. Would it not be better to use them instead of putting in the phase converter? Is this not a simple matter of detail, a matter of compromise, between the mechanical objections to running the extra trolley, and the objections to putting a little more apparatus on the locomotive? It is really calling on the electrical system at the two ends to bear the brunt of the mechanical objections to the additional trolley. If the three phase system had been employed on the line as well as the locomotive there would have been required two overhead high-voltage contact wires instead of one; two current collecting devices on each locomotive instead of one; two oil switches instead of one; transformers for three phases instead of one; a three-phase motor for driving the blower and compresser instead of a phase converter which serves the double service of phase converter and motor.

It has been alleged that the induction motor does not permit a higher speed on level track: but in this particular case the change in the number of poles secures a speed of 28 miles, or double that employed on the grade. This is a higher speed than would ordinarily be obtained from a direct-current equipment.

True, electrical engineers do not agree among themselves, on all plans and details. But, our variations are no wider than those in steam locomotive practise. The problems which the steam locomotive designers have been working on for nearly a century, have been solved electrically. A kind of apparatus was required which had not been built before, combining together a great many new types of elements, and a great many elements

of common type, but designed in new fashion, so that they can work together on a large scale, and we utterly outdistance steam practise.

If the new locomotives are hauling more coal and giving railway service superior to any ever given before, it is a little uncomplimentary, at least, to say—"Well, that is probably the least unsatisfactory thing that could be done." Of course it is, if we have done the best thing possible, exceeding anything which was done before, of course it is the " least unsatisfactory." That particular system is best which in a given case performs the service at the least cost.

William Arthur: When you stand back and look at what has been accomplished on an electrification such as the Norfolk and Western, you get a new perspective. Talk, such as we have heard about retainers, whether single-phase generation was highly efficient, when compared with some other system, and other relatively unimportant details seems to me very largely immaterial. The weight of the locomotives too, has been compared and one member referring to the locomotives on the Norfolk and Western, mentioned the fact that they had to carry the phase converter. A locomotive must possess weight in order to fulfill its functions. No one can conceive of a weightless locomotive doing any work. You have to get the grip on the rail and sufficient power must be applied to the wheels to maintain the adhesion which the engineers decide is necessary. That today can be done with any system. The question of the weight of the locomotive as between the various systems is today relatively unimportant, although a few years ago when we had only low voltage, direct-current and single-phase, to compare it was of more importance and there was then usually a difference between the weight of the two types for the reason that the low voltage, d-c. motor considered alone will always be lighter than a motor of the same capacity but of the single-phase type.

This is not true to-day of the locomotives as a whole. The problems entering into the weight question, the space problem, the means of ventilation, etc., are such that taking the modern locomotives of the various types and comparing them, there is but very little difference between them, To-day locomotives can be built on any system, particularly for freight service, which have practically the same weight.

H. M. Hobart: I do not share Mr. Behrend's pessimistic view that it is a question of choosing the least unsatisfactory of two very unsatisfactory solutions. I think it is a question of which is the most satisfactory of a variety of excellent solutions. On the other hand, I do not agree with Prof. Scott, and some others, that engineers, can say that the sole test of success is technical success. Engineers must continue to strive to get the best system possible. Because a system works and works excellently, it does not mean that it is the best system, and we will all admit

that in the long run the object is to find the most excellent system, and that is decided on the basis of dollars and cents.

It is surely not necessary at this time to review the distinguishing features of each particular system, three-phase, direct-current and single-phase. What has always exasperated me is that we did not sit down ten years ago, or earlier, and actually settle on paper that which could have been absolutely and conclusively settled on paper. I do not for my part see why it should have taken engineers ten years to conclude that the single-phase generator is out of all proportion heavier and more expensive for its output than the three-phase generator. Right up to very recently, whenever in papers or discussions I assigned to the single-phase generator any approach to its actual and now widely admitted degree of inferiority, it was stated that my representations were seriously exaggerated.

Mr. Behrend estimates a superiority of the order of 2 to 1 for a three-phase as compared with a single-phase generator. As I have already stated, it has been very difficult to find recognition of the fact that the inferiority of the single-phase generator is of such magnitude as to be of any consequence. Mr. Behrend, however, recognized this at an early date and it is of interest to recall his statement of ten years ago in an article in *Cassier's Magazine* to the effect that: "The very much reduced output of both generators and motors, if operated single-phase; the reduced efficiency; the impaired regulation; the increased heating and less stability of single-phase motors and generators, connected with the increased cost resulting from the greater amount of material required; these form the main reasons which induce me to call the recent attempts which have been made in the utilization of single-phase currents a forced idea."

Professor Scott, in alluding to the inferiority of the single-phase generator said: "What of it, it is only one link in the system?" In reference to the greater cost of a locomotive having a phase converter on it, we might say "What of it, it is only one link in the system?" But they all count up, and we must take account of each link. We are not concerned to get the most novel system, or to get something which technically works with great satisfaction, if it is economically inferior. It is quite incumbent on some one, and I have taken upon myself that duty, to remind you of what we all know very well, that the engineer must strive to obtain the most economical result.

F. E. Wynne: I agree with Mr. Hobart that it is very desirable to obtain some figures regarding the economics of operation of all electrifications which have been made. On that question, if he will refer to the last sentence of the paper, he will note that we make the following statement: "Presumably, the railway company will at some time in the future give statistics showing, better than is now possible, the heavy traffic and severe service which electrification is successfully meeting in this installation." When I wrote that I had in mind also the economies of operation

on this road. Such information was not available for publication at that time.

One of the best features in the induction motor is its constant speed qualities, which insures adherence to schedules, which the variable speed motor does not necessarily do. Like Mr. Shepard, I used to be very strongly on the other side of the fence, and thought there was no possibility of an induction motor being of any use on a railway. Following the operation of the Italian State Railways, and also having seen the operation on the Norfolk and Western, I must say that I am convinced that it has a very good field, and that the constant speed characteristic is not altogether, in fact, it is very far from being altogether, a disadvantage in this type of engine.

Mr. Shepard stated that the retainers are not used at all on this road for assistance in braking. If any other system of electrification requires the use of retainers in order to get over the brow of the hill, it is certainly a serious handicap to that system. The correction for wheel variation which is mentioned as a possibility has not yet been found necessary in practise. So far the individual motors take whatever unbalancing is found due to difference in wheel diameter. It may be found desirable to stand for the slight rheostatic losses entailed at a later date when the wheels get worn more.

Mr. Behrend's question, which he said he would ask if he dared, was why this installation was not three-phase throughout; that is, three-phase generation, transmission, conversion, distribution, and propulsion. There are two ways in which I think that can be best answered—one is that the Great Northern Cascade Tunnel, three-phase installation, has been in operation for a number of years, and since that time I know of no other case where a three-phase installation has even been proposed, not to say been installed, in this country. Second, there seems, as Mr. Behrend mentions, to be a decided prejudice against two trolley wires in this country. I think if he would go over the Norfolk and Western electrified zone he would probably also become prejudiced against the use of two wires over each track. It would be an exceedingly complicated piece of overhead work, and as there are nearly one hundred miles of trackage to be handled I hardly see why we should handicap this one hundred miles of track and the problem of collection for the sake of getting two or three more efficient generators and eliminating a certain piece of apparatus from the dozen locomotives.

Prof. Scott's characterization of the split-phase locomotive as using the electrical part of the system to relieve the mechanical part is, I think, very happy. He also inquired as to whether the performance as measured by the train sizes and speeds had ever been equalled in steam operation. So far as I know, it has not. Very frequently there have been larger trains handled, but I do not think that the combination of train size and speed on such grades has ever been secured elsewhere.

Prof. Slichter asked what variation in voltage occurs at the locomotive. So far as I know, the variation has not exceeded 25 per cent, and I think the track capacity together with the distribution layout will hardly ever permit it to exceed this value.

Prof. Slichter also inquired regarding some kind of a shock absorber for regenerated energy. The traffic on any railway of necessity at times will have valleys where there is no load being taken from the power house—it is not peculiar to the Norfolk and Western—and consequently in any system utilizing regenerated energy and supplying railway load alone, it will be necessary to provide at the feeding points, either substations or power house, a rheostat which will absorb the regenerated energy when there is no other load on the line. Such a rheostat is in use on the Norfolk and Western and operates a few times in the course of a day.

In this discussion, there has been a tendency to emphasize details and to determine which present system is the least disadvantageous, or whether any one is the most advantageous. I think that is a biased point of view to take. We are all trying to improve the art of electric railroading, and I believe that every one here will agree that an art which has only thirty years' of history behind it is not yet perfected. There is probably no one electric railroad system that is as yet perfect. We hope that some day the various systems may be perfected, and that it may be possible to determine for individual cases which is the most advantageous system; and if such a thing is possible, we should like to see a single system on which we may standardize. I think it will be some years before we get to any such point. Electrification is entirely too new and young at the present time.

Discussion on "The Liquid Rheostat in Locomotive Service" (Hall), New York, February 9, 1916. (See Proceedings for February 1916.)

(Subject to final revision for the Transactions.)

C. D. Knight: The ordinary industrial liquid rheostat, Fig. 1, used considerably for mine hoisting work, consists of a large tank with a chamber at the top containing the electrodes and movable weir controlled through a system of levers by the hoist operator. The position of this weir determines the level of the water.

An electrically operated pump having usually a capacity of about 300 gallons a minute pumps the electrolyte from the lower part of the tank to the upper chamber in a predetermined period, usually five to twelve seconds. When the weir is brought to its lowest position the upper chamber is emptied, the electrolyte dropping into the lower part of the tank, where its temperature is lowered by means of cooling coils.

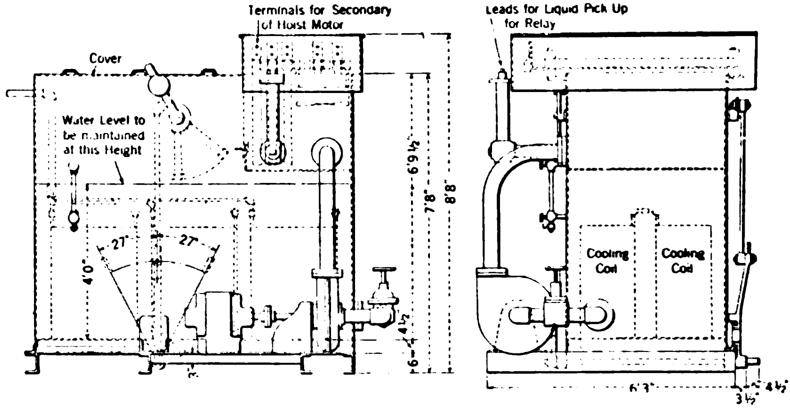


Fig. 1

Mr. Hall has told us that his method of cooling the electrolyte is by running it over a certain number of cooling trays. The capacity of a liquid rheostat depends to a great extent on the safe running temperature at which the electrolyte can be maintained. As Mr. Hall has shown us only the general construction and overall dimensions of his rheostat without any information regarding the cooling trays, I should like very much to have him give some further information with reference to the size and cooling capacity of the trays; also some information regarding the electrical characteristics of this rheostat. In other words, what amperes and volts can be carried for intermittent and continuous duty, as there are very few figures in the paper, which would go to show the actual capacity of the device.

The characteristics of induction motors require more or less resistance in the rotor circuit for relatively long periods, and considerable energy must be dissipated. How much does this

amount to, and how much water would be evaporated under operating conditions? He states that in this type of device you can use as much water as you please, bearing in mind that there is a big supply of water for cooling, I should like to know how he keeps a constant solution if he is continually evaporating the electrolyte and refilling the tank with fresh water.

Mr. Hall also states when the rheostats are full of liquid the proper switches are closed, short circuiting the motor secondaries, and that these short-circuiting switches do not come in until the operating mechanism is in the "full on" position. I wish to ask Mr. Hall if he has any interlocking arrangement, which insures that the motor secondaries are not short circuited during the accelerating period of the motor.

R. E. Hellmund: Mr. Knight asked how large the cooling tower for the water is. As far as I remember, each of the cooling towers in which the water runs down and the air goes up. is about four to five feet high, two to three feet wide, and two feet six deep. It is very small as compared with anything else that could be done. The reason, as mentioned in the paper, is that the water evaporates and heat is dissipated in that manner.

Regarding the capacity of the tower, I might say that at times the rheostat for one of the cooling towers takes care of 800 amperes with about 750 volts to start with during accelerations for periods of five or ten minutes, or even longer, and I have also seen it operate for periods of ten or fifteen minutes at one time; when the signals are against the train these loads are often repeated several times without causing trouble of any kind. The only difference that can be noticed under such severe conditions is that some steam comes out of the cooling tower exhaust.

As mentioned by Mr. Knight, the evaporation of the water will, as a matter of course, change the solution, but we find that the rheostat is not at all sensitive in that respect, and by adding a few gallons of water about once in twenty-four hours, it can easily be taken care of.

Mr. Knight asked if there was any interlocking system which assures that the short-circuiting switches do not come in until the water is at high level. There is such an interlocking system, consisting of contacts which are located at the top of the rheostat, and are closed by the water when it gets there. This insures the reliable operation of the rheostat.

Discussion on "Chattering Wheel Slip in Electric Motive Power" (Eaton), New York, February 9, 1916. (See Proceedings for February 1916.)

(Subject to final revision for the Transactions.)

S. T. Dodd: It occurs to me that chattering wheel slip is exactly the same phenomenon which has been reported on a good many European side-rod locomotives. Of course, the European designers have had more experience than we have had in designing various types of side-rod locomotives, and there have been reported in the foreign technical press several failures of this type of locomotive. I have in mind principally a couple of reports in German papers in regard to the Loetchberg locomotives. These locomotives, as you will remember, have characteristics which would increase the possibility of such a thing occurring. They have two very large motors of about 1300 h.p. each, geared to jack shafts the jack shafts tied together by Scotch yokes, which in turn are connected to the driving axles by side rods. In the papers I have in mind, they describe the disturbance in these locomotives, as a " shuddering " motion occurring at speeds of 20 to 25 miles an hour. This is so intense as to break the cranks and the Scotch yokes, sometimes by tearing them apart by tension, and sometimes crushing them by compression. The papers I have made reference to discuss mathematically the motions and the stresses which occur in such a frame work as that, showing that these forces are proably due to the building up of mechanical resonance between the springing of the driving rod on one side, and the inertia of the very heavy armatures on the other.

As far as I can see, that is what Mr. Eaton describes in his paper, in clear physical language, where the German writers describe it mathematically. The cure which the mathematical analysis pointed out was the introduction of springs of considerable amplitude of motion as compared with the amount of displacement you would ordinarily get in the side rods. By inserting springs whose amplitude of motion could be measured in inches rather than in thousandths of an inch, they expected to eradicate these troubles. For the Loetchburg locomotives, spring gears were ordered sometime before the European war, but I have never heard that they were installed, or the results if they were installed.

The question which occurs to me is whether Mr. Eaton's chattering wheel slip is not another phase of exactly the same phenomena which appeared on the Loetchburg road and on many of the European locomotives, and whether a cure for it would not be found in exactly the same thing which was found as a cure for the European locomotives, that is, the introduction of a certain amount of spring, with a certain amplitude of motion and, with a dead beat action which would damp out these oscillations before they could build up to any considerable extent.

W. I. Slichter: About ten years ago I was called on to make some calculations as to the effect of the pulsating torque of single-

phase motors on the gears and transmission between the motors and wheels, and when I got my equation of friction, inertia and mass and elasticity of the material, I found I had an equation like that of a single-phase circuit, with resistance, inductance capacitance, and as soon as I had the equation I saw the solution—change the inductance or capacitance so you no longer have resonance, and the chattering would disappear.

Charles F. Scott: About six months ago Mr. Eaton was called down to the West Virginia mountains by telegraph to diagnose this difficulty described in the paper. He found that the wheels were slipping. His problem was to find out why they were slipping, and what to do to prevent it.

He had at hand for his investigation of this oscillation all the refinements of the railway repair shop for supplying his physical apparatus, and his own initiative and ingenuity for devising the means of proceeding with the facilities at hand. The oscillations were scratched on a long strip of iron about 1/32 of an inch thick, and three or four inches wide, attached to the circumference of the driver. A sharp point was drawn across when the wheel began to slip. He had to try a good many times to get a record, and his actual record was a little scratch line on the rough piece of iron. Then taking that little wavy line, drawing tangents to it, getting the change in the rate of acceleration at different times and taking the moment of inertia of the wheel, he calculated the forces required for producing the recorded acceleration. Apparently, it was a very coarse, crude method.

Looking at that connecting rod, you would think if anything was solid and would stay together, it would be that great big steel rod. It is apparently quite a number of inches wide and several inches thick. He wanted to find out how much the rod was being stretched, and what was the variation in length of the rod during the slipping. That kind of measurement would ordinarily require microscopes, and other apparatus which a well equipped physical laboratory would afford. He proceeded to the repair shop and got a strip of iron and riveted it to the rod at one end—and attached it by a piece of lead at the other end. After this rod had gone through its vibration, he finds that the lead has changed a little in size, showing the amount of change of length between the great big side rod and the little constant length rod attached to it. Then from this elementary, simple method of measurement, he finds a very close agreement with the measurements made with scriber on the circumference of the driver.

W. L. Merrill: This same phenomenon has been known and has given trouble for years in ordinary metal cutting, that is, I refer to lathes, principally. Now, undoubtedly the tires of the locomotives we have been discussing here had the same trouble develop when they were being turned up, if too hard a cut was taken. The matter is not serious, except in some kinds of drive. For example, a punching press which is foot operated; that is,

a fly-wheel is running all the time and the clutch thrown by a lever, if the press is driven by an individual motor, and this motor is controlled by an automatic starter, which depends on current flowing through some part of the mechanism for holding home the controller or the starter in the full-on position. If we have a heavy cut to make with this press, upon the releasing of the load as the die travels through the stock, the twist or whatever you gentlemen choose to call it, that is put in the gearing mechanism at the time the fly-wheel is giving up its energy is immediately reversed the other way, and the current reverses through the motor, the motor shuts down and the machine stops. That is a simple matter and can be taken care of by putting on a type of starter which depends on voltage instead of current for holding it in position.

The same thing occurs on lathes, when driven through the back gear, and several sets of gearing between the point of application of power which may be a belt, if too heavy cuts are taken or the angle of the tool is ground improperly.

I mention that as being exactly the same thing as what we are discussing in the slippage of the wheels.

G. M. Eaton: Referring to Mr. Dodd's discussion, there is a point of inherent difference between the chattering which occurs at the time that the wheels are slipping, and the "shuddering" which Mr. Dodd refers to as having occured in various rod-connected European locomotives. This "shuddering" is a true synchronous action occurring at a certain critical speed, and at higher multiples of this critical speed. When this "shuddering" takes place on a given locomotive and at a given speed, it is of a practically uniform frequency. Contrasted with this, the chattering occurring when the wheels slip, may be over a surprisingly wide range of frequency. The writer has observed it, (at a frequency per second of 3½, about 4, about 5, about 6, and up to as high as 33), on a given locomotive under conditions where the only observable difference was a probable variation in co-efficients of friction between the drive wheels and the rail.

This erratic action can be explained only by the presence of at least one very widely varying function, and this condition is met by the characteristics of friction between the rail and the drive wheel.

The illustration brought out by Mr. Merrill fits very much better. In a lathe, the action of the tool in producing the chip may cause alternate smooth running and breaking of the chip, and this will provide the necessary setting for production of vibration. There are two or three other actions which may occur and give the necessary conditions. Cuts of various depths will alter the frequency.

Chattering wheel slip has occurred in various locomotives where true resonance at high speed running has never occurred, thus showing conclusively that the setting is different for the production of erratic chattering slip, and true resonance.

DISCUSSION ON "A METHOD OF DETERMINING THE CORRECTNESS OF POLYPHASE WATTMETER CONNECTIONS" (KOUWENHOVEN), NEW YORK, FEB. 9, 1916. (SEE PROCEEDINGS FOR FEBRUARY 1916.)

(Subject to final revision for the Transactions.)

W. H. Pratt: The author has made a very large amount of painstaking effort in collecting and analyzing the behavior of the meters with these miscellaneous connections. There is one point that is emphasized throughout the paper, that this checking must be made under balanced load conditions except in one particular case. There should be a great deal of care exercised in deciding whether you have a balanced condition in applying the check. The fact that you use a motor which tends to take a balanced load does not necessarily mean that the load will be balanced unless the voltages are strictly balanced. A very small unbalancing of voltage may mean a very large amount of unbalancing in the power station. This point emphasizes the fact that you should always be very particular in following the diagrams of connections. It is a very easy matter to systematically arrange most work so that you can follow the diagrams just as if you had a column of figures to add, and then very carefully do the work. There is a temptation, however, to rely on the check, but a check should be made bearing in mind that you have limitations which might seriously affect the conclusions.

Again, if you find that you have trouble it may be a very difficult matter to locate the cause of it. I have in mind a case which was called to my attention not many months ago in which all ordinary checks applied indicated that the connections were correctly made, even to tracing out the wiring, but there was evidence of something seriously wrong. When we came to trace it down, it appeared that there were two sets of instruments on the switchboard, the switchboard being in two parts, and the connection that was supposed to be a ground connection, simply served as a common zero potential connection. The two parts of the board were each individually connected up all right, but it so happened that the instruments on one portion required to have a common connection with the instruments on another portion, and this common connection was omitted, and there was a most mystifying behavior of the apparatus.

The author says that meters which he designates as class C meters cannot be used with either voltage or current transformers. Of course, it is quite possible to use such meters by making interconnections of the circuit, and making a simple interconnected secondary network.

Again, the remark is made: "By the use of the table it is also possible in cases where incorrect or open connections are found, to determine from the meter readings, when the conditions of the circuit are known, the actual kw-hr. that have been used." I think the expression of the author "when the conditions of the circuit are known" should be very much emphasized, because ordinarily the conditions of the circuit are such that the loads

are not of definite power factor, and unless that is true throughout the whole period of operations, no conclusions could be drawn.

G. A. Sawin: The author's methods of making his calculations are the same that I have followed for some years, but I have laid out my diagram a little differently. For example suppose we find a meter connected in a certain manner Fig. 1 and desire to know its accuracy; we make a diagram, Fig. 2. We find the current coil of element A is in line 1, and the current coil of element B is in line 3. The potential of element A is connected from 1-2 and of element B from 3-1 as shown. I have shown an incorrect connection for the purpose of illustration. Now we must always remember that the meter records exactly what it received, no matter whether it is the true power or not. In other words, if we treat each element in this case as a single-phase meter, and remember the measured power equals the voltage received times the current received, times the cosine of the angle of lag between this particular current and potential, we will immediately see what each element is measuring. Add the results of the two elements together, and we will have the total

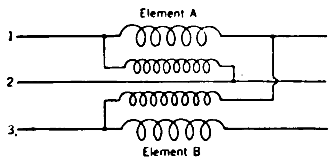


FIG. 1

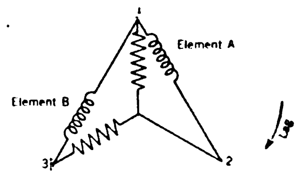


FIG. 2

measured power. Compare this result to the true power, and the correct answer is obtained. In this case the measured power is $E\,I\cos(30° + a) + E\,I\cos(30° + a) = 2E\,I\cos(30° + a)$.

The diagram to me personally is clearer, and shows exactly how to arrive at correct results in any case.

Mr. Pratt has called attention to the fact that in applying the author's method, we must have a balanced load. If we have an unbalanced load the results will not always come out, as expected. We often find cases where we have single-phase motors connected across two of the wires of the three-phase circuit, and sometimes we have lights connected so that in practise we should apply this method with caution.

Another point which the author does not bring out, but which is important, is that, after a meter has been in service for some time, we do not know whether it is in correct calibration or not. The author assumes all through his paper that the meter he is dealing with is correct. We can very readily imagine the case of an incorrect meter, for example, one which is badly out on lag, which would not answer correctly the test given here by the author. Therefore, in practise we must bear in mind, the

balanced condition of the load and whether the meter is correctly or incorrectly calibrated.

L. W. Chubb: We must remember that there are two classes of men that take care of meter connections—there is the engineer who knows the vector relation of the voltage and current, and if he gets irregular results in one way, he can usually ferret out what is the matter, either by symmetry of connections or by common horse sense. The station man who gets into trouble, must be provided with some rule of thumb method which will give him results and not require basic knowledge of the principles involved. For this reason I think Mr. Kouwenhoven's scheme of reversing the potential coils for two classes of meters, or else opening the current between the meter and power in the other class, is of great value.

The requirements for balanced load in the majority of the work is, as Mr. Pratt says, a handicap. A balanced load on such a thing as an induction motor, or light running synchronous machine, is rare. If the field distribution in the motor does not agree with the line wave, there will be quite a big distortion and an unbalancing of curren.s with a very small change in phase and voltage. I do not believe this is a serious handicap, however, as you can estimate about what load you have, and if the meter comes nearly to a standstill, you know that the connection is probably right. The same is true for a meter a little bit out of calibration in the two parts, as the last speaker has mentioned.

I think, that for the engineer who goes out on a meter job and wants to find out what is wrong, the old method of opening one element of the polyphase meter and then the other is pretty good. You can usually get a load, balanced or unbalanced, which will have a power factor both above and below 0.5. For instance, the usual transformer of today on open circuit is run at such an induction that the exciting current is below 0.5 power factor. It is easy enough to put additional load on the transformer, and take another reading at a power factor above 0.5 so that opening one element at a time, with the two tests, will give quite a reliable result.

Comfort A. Adams: The subject of polyphase meter connection is so often made unnecessarily complicated that I am going to take enough time to explain what seems to be the natural and simple point of view, which I have employed for more than twenty years.

Label the mains of a three-phase system, a, b and c. Count the currents in a and b as positive when flowing outwards from the source and the current in c positive backwards. Then will $i_a + i_b = i_c$ at every instant, and c may be looked upon as the common return for a and b. The total power flowing outwards from the source will then be that of two circuits ac and bc, or stated in symbols, $e_{ac}\, i_a + e_{bc}\, i_b$, which holds for every instant of time irrespective of whether the system carries direct, alternating or pulsating current.

The two single-phase wattmeters or the two parts of a three-phase wattmeter connected with their currents coils in *a* and *b* and their pressure coils across *ac* and *bc* respectively in the direction indicated by the symbols, will measure the average values of $e_{ac}\, i_a$ and $e_{bc}\, ib$ respectively, or a three-phase wattmeter will indicate the sum of these, *i. e.*, the total power flow of the system in the direction indicated. If the corresponding terminals $\pm$ of the current and pressure coils of each meter are so indicated or implied by their location, it is only necessary to connect the two current coils in the lines *a* and *b* in the direction of power flow and the corresponding pressure coils in the directions *ac* and *bc*. If the direction of power flow is not known, it may be assumed and connections made accordingly. If the assumption is correct, the meter will read or run positively, otherwise either both current coil connections or both pressure coil connections should be reversed.

The above proof of the two wattmeter method of three-phase power measurement as well as the resulting conclusions as to the method of connection, is absolutely rigid and general for any wave shape or no wave shape. Moreover, it is directly applicable to a system of n wires in which one is looked upon as the common return for $n - 1$ phases, and the power can be measured by $n - 1$ wattmeters (or wattmeter elements of a polyphase wattmeter) connected as above indicated for the three-phase case.

I realize that the problem faced by the meter man is not the same as that faced by the laboratory man; but I feel quite sure that even the practical meter man would find his problem vastly simplified if he could acquire the above described natural point of view.

The idea is not at all a new one, but so few engineers seem to make use of it, that I am impelled by my teacher's instinct to set it forth again.

W. B. Kouwenhoven: As stated in the paper, the term correct refers only to the direction of rotation of the disc of the watt hour meter used in this investigation, and has nothing whatever to do with the accuracy of the meter. The meter used was not calibrated before making the investigation and it had seen a number of years of service. I do not know whether the two single-phase elements had exactly the same characteristics or not. However, their characteristics were sufficiently alike to cause the meter to stop when the voltage connections to phases 1 and 2 were interchanged. If a polyphase watthour meter is so badly out of adjustment that it will not answer correctly to the test although connected properly: then its failure to meet the test will immediately indicate that there is something wrong with the meter itself.

As Mr. Chubb pointed out, a slight unbalancing of a three-phase load such as is often found in induction motors, especially when operating on light loads, is not serious, and the check produced by the interchange of the voltage leads will identify the

correct connections. Part of the investigation was carried on with induction motors as load, and part with synchronous motors, and in neither case was there the slightest difficulty in recognizing the correct connections when the check was applied. I do not know the amount of unbalancing that would prove serious. The correctness of the connections on balanced or unbalanced three-phase circuits for any class of meter may be checked by removing the fuses from the line as described in the paper.

If a polyphase watt-hour meter is placed in a circuit where no instrument transformers are required, then its proper connection, as Professor Adams points out, is comparatively simple. If two voltage and two current transformers are added to the circuit then the connections become difficult and a check is necessary.

Discussion on "Classification of Alternating-Current Motors" (Fynn), and "The Classification of Electromagnetic Machinery" (Creedy), Deer Park, Md., June 30, 1915. (See Proceedings for May and July, 1915).

(Subject to final revision for the Transactions.)

A. S. McAllister: Mr. Creedy mentions several types of motors according to his classification, (*A*), (*B*), (*C*) and (*D*). Under (*A*) he includes balanced polyphase machines and under (*B*) he includes elliptical field machines, such as single-phase and unbalanced polyphase apparatus. He states that the elliptical field machines must necessarily have a commutator. Therefore, in the elliptical field machines he does not include the single-phase induction motor without a commutator.

I wish to call attention to the fact that an elliptical field machine does not necessarily have a commutator. An elliptical field, if I have a proper idea of what the author means by that term, is a field which is elliptical in time and space.

The author calls attention to what he says is a new type of machine, which has never been discussed, so far as he is aware. He refers to what he has provisionally called the compensated inverted repulsion motor. He is evidently familiar only with English practise, because the machine mentioned by him has been fully set forth in the records of the Patent Office of the United States.

Mr. Fynn has called attention to certain fundamental principles in the operation of commutator machines; the division of the machine into its two parts, the torque-producing field and the current which produces the torque against the field. I believe that practically all of the differences in opinion of people who are more or less familiar with the various types of machines have been due to the fact that they have ignored this one fundamental principle. In order to determine how a machine operates, one must divide it up according to the principle laid down by Mr. Fynn. I believe that there is no other logical and proper method. There may be other methods of defining what is meant, but in the end, if one wishes to determine the characteristics of the machine, he must base his equation on assumptions which must be identical with what Mr. Fynn has presented in order to get correct results.

H. M. Hobart: The work of the Standards Committee will be much assisted by these two papers. I should suppose that the sub-committee of the Standards Committee which deals with nomenclature would give careful study to both papers, and profit by the suggestions. I doubt, however, whether either the one scheme or the other, if adopted, would work out very well in practise. It seems to me that Mr. Fynn's object can be accomplished much more effectively by regarding his names more as *abbreviated definitions*. As such they are exceedingly useful. For practical use we need something much more brief than some of these many-worded titles. It is enormously diffi-

cult to force the use of terms. I do not recall exactly when it was, but at one time the American Institute of Electrical Engineers decreed that a certain machine should no longer be called a rotary converter, but should be called a synchronous converter. Unfortunately the former designation is still the more usual. I take that as a single but typical instance.

The papers we have considered this morning are very important and useful contributions to a very difficult subject. When we hear some one allude to a repulsion motor, there is vividly conjured up in our imaginations the type of motor to which the man refers. The correctness of the designation is immaterial. If some one speaks to me of a Mallet, I see vividly at once something which, if he gave me a full description of it, he would have to talk about for a long time. It means a distinct type of locomotive. He might have to qualify it by giving certain details of it, this, that or the other kind or size of Mallet, but the general type of machine is brought, like a flash, into my mind when he speaks of a " Mallet." This would not be the case if you speak of its articulated construction, number of axles, arrangement of driving wheels, etc. He alludes to it as a Mallet, and I know what he means. He is alluding to a special thing, which my mind immediately grasps.

While we cannot *always* approach this degree of brevity, there are plenty of similar instances. For example, we speak of the Hall effect, the Peltier effect, the Wheatstone bridge, the Blake transmitter, the Siemens dynamometer, the Kelvin balance, the Edison battery and the Daniell cell. The name of the man associated with the conception or development of a certain class of apparatus appeals to us very strongly, and this association of the man's name with the apparatus becomes very useful in identifying these things. It really does not make any difference whether the credit is correctly bestowed or not. We do not really care whether a man named Mallet first conceived the particular type of locomotive bearing his name. We know it as an object called a " Mallet," and that means much to us, quite dissociated from the fact that Mallet was the man who invented the engine.

The fact is that in this particular subject under discussion the names which have, rightly or wrongly, come to be associated with these motors have already helped a great deal. We cannot with certainty determine who is responsible for this, that, or the other type of a-c. single-phase commutator motor, taking that class of motors alone amongst these machines which have been mentioned. Let us confine our attention to single-phase commutator motors for the present. So many workers have been contemporaneously engaged in the development of these types of machines that it would be absolutely impossible to trace correctly the steps by which these machines have been evolved. It is sufficient that certain names are associated with cer-

tain types amongst these machines, or else with certain features of their operation. For instance, the feature of power factor correction in such a motor may be associated with a certain man's name, say Fynn. Many other names are closely associated with alternating-current commutator motors. Thus there is Atkinson, who wrote a brilliant paper on commutator motors many years ago, describing many of the types which are now becoming familiar to us in practise. Then there are Elihu Thomson, Arnold, Weightman and Heyland. At a later period we have Latour, Winter, Eichberg, Déri, Fynn, Punga, Creedy, Alexanderson, Milch, and, more recently, Scherbius and Krämer.

Now, as I say, it would not be worth while to try to figure out to which man the invention really is due—it never could be, with certainty, found out. The suggestion is just to follow the general impression and use the name which would be most naturally associated with a certain type, and it seems to me much help would be found there. The machines might be *defined* by the Standards Committee in much the way that Fynn and Creedy suggest defining them. Mr. Fynn's designations provide brief, compact descriptions of each type of motor. We must remember that other features already taken into account in the Standardization Rules also come into consideration. These relate to degrees of enclosure, regulation, etc. We should simply give a brief name to one type of alternating-current commutator motor, and then state whether it is of the enclosed or ventilated type, the particular kind of ventilation, and the output, speed, periodicity and voltage and also whether the rating is short time or continuous. There are many features requiring mention, so if we can use a man's name, (or any familar word, such as "repulsion"), as the means of describing the fundamental type, it will afford us great mental relief in many instances. I want to offer this suggestion for the consideration of the Nomenclature sub-committee of the Standards Committee.

Charles R. Underhill: This matter of definitions of motors is, perhaps, a little out of my line, but I am very much interested in the matter of standardization. Mr. Fynn's attitude in calling a neutralized single-phase series motor a neutralized single-phase series motor appeals to me very strongly. It tells what it is, and you do not have to look up the matter in the dictionary to find out what it is. On the other hand, I note that Mr. Creedy has shown a tabulation where he has used some symbols, some of them look like chemical symbols, but anyhow, it gives a condensed form of classification. You have all heard of the Taylor system, no doubt. In the company with which I am connected we never make the same article for two different customers. Everything is made on special contract, and large quantities are made, yet we have absolutely no difficulty in the classification of all of these things, not only the apparatus and type but the material as well. The Taylor system is a scientific thing and scientific management is becoming a recognized institution.

To begin with, let us take the former classification; let us take a neutralized single-phase series motor. In the first place, we can say that it is a motor. Any manufacturer of electrical apparatus in general who makes motors would know when seeing the symbol *M* that it stands for motor, and in the next position after it is placed the letter *S* which shows it is a series motor, and in the next position after that might be placed another *S* meaning that it is a single-phase motor. Then that could be followed by the letter *N*, which would show that it is of the neutralized type.

The symbol would then be *MSSN*.

In the Taylor system under this general classification come the sub-classifications, which naturally follow for the details.

Let us consider the practise of the manufacturing company referred to above. The symbol *KE*600*C*9187 *VB* is an example of the designation of the finished product. *K* = coil; *E* = enamelite wire; 600 is the resistance in ohms, *C* indicates that the coil is of the controller type, 9187 is the code number, *V* means that the coil is treated with insulating varnish, and *B* indicates that the coil is mounted on a brass tube. Sometimes the dimensions are inserted between the letters in the symbol. The parts which enter into the construction have similar symbols, and the symbol for the parts, in the example cited, would begin with *K V*, meaning "for coils for various purposes", other following letters and numerals representing the material and dimensions.

The Taylor system is being used more and more by large manufacturing concerns; it is standard; is already in existence, and it seems to me that some form of classification in connection with those suggested in the papers would work with this system of scientific management right from the start.

H. M. Hobart: There was a technical matter in Mr. Fynn's paper which might be worth mentioning. I can combine and resolve *causes*, but I find it dangerous to try to combine and resolve effects. Mr. Fynn considers component fields. I get along fairly well as long as I consider component m.m.fs., but believe it is dangerous to deal similarly with the fields resulting from these m.m.fs. Such a plan is, in my opinion, beset with pitfalls. Mr. Fynn, in connection with his condemnation of the term "repulsion," laid special stress on the importance of not leading students astray by referring to a certain type of motor by a misleading name. Does he not run the risk of leading them astray in this other direction? I have struggled with Mr. Fynn's various papers during the last ten years and have found it necessary to look out for these pitfalls where he alluded to the component fields. I should like to know whether others have had similar experience, and whether it is agreed that I am right in my opinion that it is practicable and useful to combine and resolve *causes*, but that there is something wrong in trying to do that with *effects*.

Comfort A. Adams: This is a subject which I have had frequent occasion to discuss as a teacher, as much confusion is sure

to develop in the mind of the average student unless he is thoroughly prepared to distinguish between the imaginary component fluxes and the real resultant flux. Nevertheless, it is in many cases absolutely necessary to compute these several component fluxes, often more than two, as if they existed separately, because of their intimate relation to the operating characteristics of the machines in question. Take, for example, the leakage fluxes of an induction motor; we speak of these as several independent fluxes, whereas we know as a matter of fact that they are mostly distortional in their nature and parts of the real total flux; that is, we artificially subdivide the actual flux into several components and compute them as if they were independent. There is a real danger here, and Mr. Hobart is quite right in emphasizing it; but it can be avoided by a sufficient emphasis upon the fact that the consideration of the component fluxes as separate fluxes is artificial and merely an aid to visualization and computation.

V. A. Fynn: I think I can answer Dr. McAllister's question as to Mr. Creedy's paper. I may be wrong, but it appears to me that Mr. Creedy includes the single-phase induction motor under (*A*), for he says: "Our principles of classification do not necessitate any distinction being made between single-phase and polyphase machines so long as the fields of both remain circular." I think Mr. Creedy believes that the field of a single-phase induction machine remains circular, and that this motor is therefore to be classed with polyphase motors.

It strikes me that Mr. Creedy's classification does not go quite far enough, and is based on incorrect conceptions. I think it is important, when talking to some one about a particular machine, to indicate clearly whether reference is made to a single-phase or a polyphase machine. The differences are quite essential. To illustrate this, take Mr. Creedy's contention that the machine shown in Fig. 19 does not necessitate a distinction being drawn between the single- and the three-phase case, for regulation is obtained in exactly the same manner in both. I do not agree with him at all. Mr. Creedy proposes to regulate the single-phase machine, Fig. 19, by injecting an e.m.f. into what I call the armature circuit. The result is to either lower or increase the speed without changing the magnitude of the field in the vertical axis. But if the speed is increased or decreased, the magnitude of the field in the horizontal axis is changed. If you apply the same method of regulation to, say, a two-phase motor, then you change its speed but do not change either its vertical or its horizontal field. The reason is simple—in the polyphase motor the rotor acts as an armature in both axes, while in the single-phase machine it acts as an armature in the vertical axis and as a field in the horizontal axis. In the single-phase motor, a change in speed alters the magnitude of the horizontal or motor field, whereas all motor fields in a polyphase motor depend on the e.m.f. applied to the stator windings and are independent of the speed.

Mr. Creedy has stated that he preferred to leave things as they are and not change well-established names. He, however, refers to the d-c. series machine as *C-Al-P-L-Se*, which is probably a mistake for *V-Al-P-L-Se*. If we translate this we get: Variable intensity field, secondary power zero, commutator on primary, low frequency magnetization, series motor, as a substitute for the generally accepted name, d-c. series motor. Note that after we have said all Mr. Creedy suggests, nobody will know whether we have reference to a d-c. or to an a-c. machine, whether it is neutralized or not, and if neutralized, whether it is so conductively or inductively.

I think Mr. Hobart's suggestion, to give coined names to these various motors, is well worth considering. I do not care whether the names agreed upon are the names of the alleged inventors or coined words just like the word "repulsion," but I clearly see the difficulties of such a course. Some of us lay claim to the invention of several motors, and a dictionary defining the meaning of coined words will be indispensable. For my own part I will be very glad to accept the word repulsion, but before agreeing to it, a definition of the term must be insisted upon. Apply the term repulsion motor to any machine you care to select for the purpose, but confine its use to that particular motor, for the term can have but one meaning.

W. C. Korthals Altes (communicated after adjournment): In Fig. 13, Mr. Fynn shows the well-known repulsion motor and suggests as a substitute for this historical name, "self-excited single-phase series induction motor with rotor excitation".

I think it is unnecessary to raise serious objections to any attempt to introduce this name. The well-known American habit of shortening even the simplest Christian name is the best safeguard against such a mouthful being imposed upon us.

In Fig. 14, he shows the same repulsion motor with a somewhat different arrangement of the stator winding and suggests the name "single-phase series induction motor".

In his descriptive outline he mentions that with a motor according to Fig. 13, "the power factor rises to near unity at about synchronism", while with a motor according to Fig. 14, " the power factor is low at all speeds ".

I have never known of this marked difference between these two motors and should like to ask Mr. Fynn whether he has found that his theory is confirmed by test.

In Fig. 1, I have shown a bipolar repulsion motor having 12 stator slots, containing a concentric stator winding, the brushes being shifted over 30 deg. The stator winding can be resolved into a component consisting of the conductors lying between the angles *aOb* and *cOd*, which excites the field flux, and a component between the angles *bOc* and *dOa*, which constitutes the compensating winding, from which the power is induced by transformation into the rotor. In opposition to Mr. Fynn, I contend that the current between the brushes will assume such a value

that the secondary ampere-turns of all the rotor conductors equal the total number of stator ampere-turns lying between the angles *bOc* and *dOa*. This applies to standstill, when the ampere-turns required for exciting the transformer flux can be neglected. When the motor is running the transformer flux will increase with the speed and the secondary current will assume such a value and time phase that the vector sum of the secondary ampere-turns and the ampere-turns lying between the angles *bOc* and *dOa* excite the transformer flux. This corresponds to what happens in any stationary transformer.

My Fig. 1 corresponds to Fig. 13 of Mr. Fynn's paper. In Fig. 2, I have shown the motor which corresponds to his Fig. 14. It is clear that as far as the ampere conductors in the stator slots are concerned and their position in regard to the brushes, my Figs. 1 and 2 are identical. The only difference is that the con-

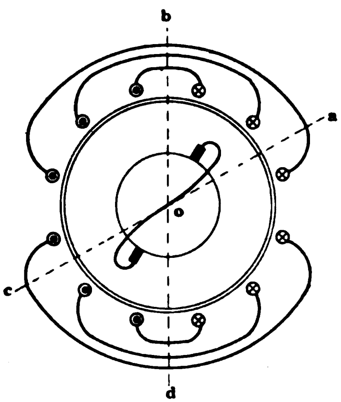


FIG. 1

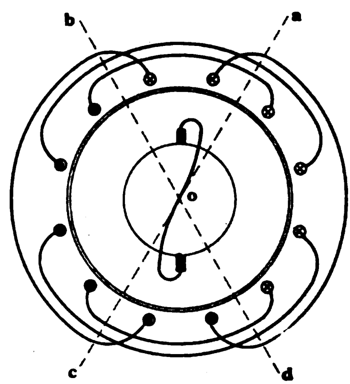


FIG. 2

ductors exciting the field, lying in both cases between the angles *aOc* and *cOd*, are interconnected by longer end-connectors in Fig. 2 than in Fig. 1. This means a slight increase in leakage reactance. Bearing in mind that commercial repulsion motors have about 10 per cent leakage reactance in the stator, it will be appreciated that this increase in reactance is only very slight, and cannot so materially affect the power factor as would follow from the above quoted statements by Mr. Fynn. In any case it seems perfectly arbitrary and contrary to fact to speak in one case of rotor and in the other case of stator excitation.

In Fig. 3, I have shown the same twelve slots as in Fig. 1, the conductors in these slots being connected by a Gramme ring winding. It is clear that Figs. 1, 2 and 3 are identical, with the exception that in case of Fig. 3 the reactance of the end-connections is considerably higher.

That Mr. Fynn has an unusual conception of what is generally understood under rotor excitation is further illustrated by his

outline of the theory for the motor shown in his Fig. 18. He claims that this motor has the same characteristics as the one covered by Fig. 13, "with this difference, that the whole rotor winding is made use of".

This motor is, however, fundamentally different from the one shown in his Fig. 13, as it has what is generally understood by rotor excitation, which offers the possibility of operating the motor with approximately unity power factor at synchronism and full load.

A physical conception of what is generally understood by rotor excitation can readily be obtained by the following simple experiment.

A two-pole d-c. armature is driven by means of an auxiliary motor at approximately synchronous speed inside the stator

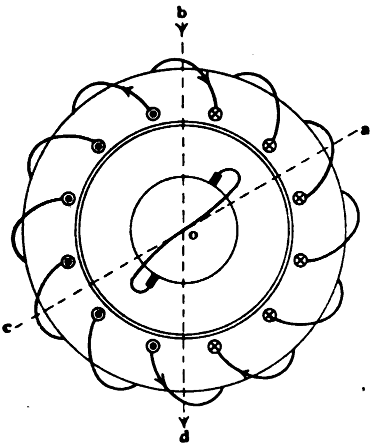


FIG. 3

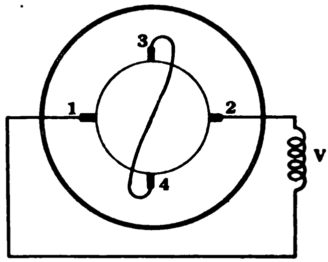


FIG. 4

of an induction motor. On the commutator slide four brushes, spaced 90 deg. apart and connected as per Fig. 4. If we apply a small a-c. voltage v as shown in Fig. 4, then a current will flow between the brushes 1 and 2 which excites an alternating flux along an axis coinciding with the brushes 1 and 2. Due to the alternation of the flux a voltage will be induced between the brushes 1 and 2 proportional to the flux and frequency, lagging 90 deg. behind the current. As the armature conductors rotate through this flux a voltage of rotation will appear at the brushes 3–4, proportional to the frequency of rotation and the flux. The frequency of rotation and of alternation of the applied voltage being equal at synchronous speed, the voltage appearing at the brushes 3–4 will at synchronous speed be equal to the voltage applied to 1–2. Its time phase will be the same as the current flowing between the brushes 1–2. If we now short-circuit brushes 3–4 then a magnetizing current lagging 90 deg.

in time phase behind the voltage will flow, exciting a flux, which by alternation induces a voltage, balancing the voltage generated by rotation. If the magnetic reluctance is equal in all directions this magnetizing current will be equal to the current flowing between the brushes 1–2. Again it is clear that due to the rotation through this last flux a voltage will appear between the brushes 2-1 having the same time phase as the magnetizing current flowing between the brushes 3–4, or measured from brush 1 to 2, instead of 2 to 1, will be 180 deg. ahead of the magnetizing current between 3 and 4 or 90 deg. ahead of the current between 1 and 2. We found that the current from 1 to 2 induced by alternation of the flux yielded thereby a voltage lagging 90 deg. in time phase, which in accordance with the above must be balanced at synchronous speed by the rotation voltage. Thus the voltage v can be in time phase with the current flowing from 1 to 2 and is merely determined by the resistance drop. Due to the commutation losses, leakage reactance, and core loss the speed at which the current between the brushes 1–2 and 3–4 becomes equal and the voltage v becomes a plain watt-voltage, lies somewhat above synchronism.

It will also be found that at the stator winding a voltage appears which can be adjusted to different values by changing the voltage v. The important result is, that with this arrangement we can excite a rotating field in the motor without drawing a wattless current from the source of supply. Although the phenomenon described above can be found in several handbooks, I felt obliged to describe it briefly in order to point out what by others is understood by rotor excitation, and in order to induce Mr. Fynn to give his definition more specifically.

From the above it follows that I have not the slightest objection to classifying the motors shown in Figs. 18, 19, 21, 22, 23, etc., under motors having rotor excitation. However, it will also be apparent that I do object to applying this term to the motors shown in Figs. 4, 6, 13, 14, 16, 17, etc., of Mr. Fynn's paper.

F. Creedy (communicated after adjournment): I have been much encouraged to note, on the perusal of Mr. Fynn's paper on a-c. motor classification, that the system at which he arrives corresponds to such a large extent with the one to which I have been led by entirely different and apparently antagonistic views. In order to be able to contrast the systems more clearly I have ventured to tabulate them in the two tables attached. Let us first discuss the points in which the two systems agree.

1. Series or shunt machines. Any system must preserve the classification into series and shunt types.

2. Single or polyphase. Mr. Fynn uses these words in a somewhat peculiar sense. For instance, Figs. 27 and 29, shunt machines in which the field is excited by a second phase, are classed by him as single-phase. In the sense employed by him, I maintain that his classification into single and polyphase.

machines is practically identical with mine into elliptic and circular field machines, since only *balanced* machines are referred to by him as polyphase.

3. Conduction and induction. This class corresponds very closely with my subdivision into "commutator on primary" and "commutator on secondary". The difference between them only arises in such a case as Fig. 46, where although it is a conduction motor the commutator element is nevertheless the secondary, *i.e.*, is *not* that in which the power supplied by the line is consumed.

We now come to the differences between the two systems. Mr. Fynn states at the outset that in order to arrive at a rational classification all suggestions must be based on one and the same theory and that his system is based on the component-field theory. If this were really the case, I should be obliged, from my standpoint, to condemn the system radically, as I hold that any system or nomenclature which presupposes a particular theory is an impediment to the progress of science and should be avoided. Mr. Fynn's quarrel with the term "repulsion motor" is due to its being based on a particular theory which he does not happen to hold. However, when we separate Mr. Fynn's system from his explanations we find it to be based on constructional features, methods of connection of circuits, etc., which are quite independent of any theory and therefore unobjectionable.

The terms "self" and "separate" excitation raise reminiscences of the use of the same terms in d-c. practise and hence seem confusing. Exactly the same ideas might be expressed better by such terms as primary and induced excitation. Otherwise, I see no serious objection to the nomenclature if we can decide where to stop. A comparison of Mr. Fynn's table with mine shows that he has classified a number of forms between which I do not care to make any distinction at all. It is absolutely imperative that some rule should be laid down as to how far it is desirable to go in classification, and this is, in my opinion, the crux of the whole question and the most important point brought out by a comparison of systems. I regret that I cannot agree with Mr. Fynn that he has enumerated all types of a-c. motors. He has omitted, for instance, the ordinary synchronous motor, which surely is deserving of a place, not to mention the Alexanderson repulsion-series motor and hosts of others. Two patent specifications on single-phase shunt machines, one of them in Mr. Fynn's own name, contain, between them, descriptions of over one hundred different forms, many of them differing quite as widely as some of the types Mr. Fynn lists.

It is essential that some rule be found to decide which forms deserve a place and which forms do not. The object of the system I have developed, based on energy torque and power considerations, is (a) to avoid the necessity of adopting any particular theory of operation for any type, and (b) to supply a

CREEDY'S SYSTEM

Fig. No.	Field form	Secondary power	Commutator	Magnetization	Series or shunt	
2	Elliptic	Reactive	Primary	H.F.	Series	
3	"	"	"	"	"	
4	"	"	"	"	"	
5	"	"	"	"	"	
6	"	Zero	"	"	"	
7	"	"	"	"	"	
8	"	"	"	"	"	
9	"	Reactive	"	L.F.	"	
10	"	"	"	H.F.	"	Must be treated as motor and transformer combined.
12	"	"	"	"	"	
13	"	Zero	Secondary	H.F.	"	
14	"	"	"	"	"	
16	"	"	"	"	"	
17	"	"	"	"	"	
18	"	"	"	"	"	
19	"	"	"	"	"	
20	"	Reactive	"	"	"	
21	"	Reactive (Zero at synchronism)	"	L.F.	"	
22	"	Reactive (Zero at synchronism)	"	"	"	
23	"	Derived from line by transformer	"	"	"	
24	Circular	Derived from line by transformer	"	H.F.	"	
25	"	Derived from line by transformer	"	"	"	
26	Elliptic	Reactive	Primary	H.F.	Shunt	
27	"	"	"	"	"	
28	"	Zero at normal speed.	"	L.F.	"	
29	"	Reactive	"	H.F.	"	
30	Circular	"	"	"	"	
31	"	"	"	L.F.	"	
32	Elliptic	"	Primary	H.F.	"	
33	"	Zero	Secondary	H.F.	"	
34	Circular	"	"	"	"	
35	"	"	"	L.F.	"	
36	Elliptic	Reactive	"	H.F.	"	
37	Circular	Zero	"	L.F.	"	
38	Elliptic	Reactive	"	H or L.F.	"	
39	Circular	Zero	None	H.F.	"	
40	"	"	Secondary	L.F.	"	
41	"	"	"	H.F.	"	
42	"	"	"	L.F.	"	
43	"	Derived from line.	"	H.F.	"	
44	"	Zero	None	"	"	
45	"	"	Secondary	L.F.	"	
46	"	"	"	H.F.	"	
47	"	"	"	L.F.	"	

FYNN'S SYSTEM

Fig. No.	Neutral-ization	Excitation		Conduction or induction	Series or shunt	Single or polyphase	Remarks
		Stator or rotor	Self or separate				
2	None	Stator	Separate	Conduction	Series	Single	
3	Conductive	"	"	"	"	"	
4	"	Rotor	"	"	"	"	
5	Inductive	Stator	"	"	"	"	
6	"	Rotor	"	"	"	"	
7	"	"	"	"	"	"	Two conductively related rotor circuits.
8	"	"	"	"	"	"	Two inductively related rotor circuits.
9	Conductive	Rotor		"	"	"	Two inductively related rotor circuits (Compensated).
10	None	Stator	Mixed	"	"	"	
11	Inductive	Rotor	Self	"	"	"	
13	None	"	"	Induction	"	"	
14	"	Stator		"	"	"	
16	"	Rotor	Self	"	"	"	Independent brushes.
17	"	"	"	"	"	"	Two independent rotor circuits.
18	"	"	"	"	"	"	Two inductively related rotor circuits.
19	"	"	"	"	"	"	Two conductively related rotor circuits.
20	"	Stator	Self	"	"	"	
21	"	Rotor	Separate	"	"	"	
22	"	"	"	"	"	"	Different brush connection.
23	"	Rotor	"	Induction-Conduction	"	"	
24	Conductive	Stator	"	Conduction	"	Two-phase	
25	"	Rotor	"	"	"	"	
26	None	Stator	"	"	Shunt	Single	
27	Conductive	"	Separate	"	"	"	
28	"	Rotor	"	"	"	"	
29	Inductive	Stator	"	"	"	"	
30	Conductive	Rotor	Self	"	"	"	
31	"	"	"	"	"	"	Compensated.
32	"	Rotor and Stator		"	"	"	
33	None	Stator	Separate	Induction	"	"	
34	"	Rotor	Self	"	"	"	
35	"	"	"	"	"	"	Compensated.
36	"	Rotor and Stator	"	"	"	"	
37	"	Rotor	"	Ind.-Cond	"	"	
38	"	Rotor	Mixed	Induction	"	"	
39	"	"	Self	"	"	"	Single-phase induction motor.
40	"	"	"	"	"	"	Compensated motor
41	"	Stator	Separate	"	"	Two-phase	
42	"	"	"	"	"	"	Compensated.
43	"	"	"	Ind.-Cond.	"	"	
44	"	"	"	Induction	"	"	
45	"	"	"	"	"	"	Compensated.
46	Conductive	"	"	Conduction	"	"	
47	"	"	"	"	"	"	Compensated.

precise rule as to where classification should stop. This rule is as follows:

If two different constructional forms have the same physical properties, they should be classed together.

For instance, I consider it undesirable to attempt to separate Figs. 3, 4 and 5 from one another, though there are some differences, undoubtedly. Again, Figs. 13 and 14 seem to me identical and there are a number of other pairs which I think should not be distinguished or given an apparent predominance over the thousands of modifications possible but not alluded to. Still, if the general opinion of students of the subject is that constructional forms, even if physically identical, require distinction, then probably Mr. Fynn's system superadded to a system based on physical principles, is as free from objection as any not considerably more complicated.

To my mind, however, a far better plan is to frame standard rules for deriving different constructional forms from a given form. Two such rules, which may be quoted by way of example, are as follows:

1. By means of the Steinmetz transformer reduction we may replace any inductive type by a corresponding conductive type having, not approximately but exactly, the same flux distribution and the same characteristics.

2. Any two windings on the same member which are connected in series may be compounded into a single winding, and conversely, any single winding may be resolved into two windings in series.

These two rules alone are sufficient to show that many of the types listed by Mr. Fynn are only constructional modifications of one another.

While studying the present subject, a little book by Dyhr, "Der Einphasen-Motoren," which contains an extraordinarily complete account of every type proposed or patented up to the present, should be consulted.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

ELECTRIC DRIVE FOR REVERSING ROLLING MILLS

BY WILFRED SYKES AND DAVID HALL

ABSTRACT OF PAPER

The manner in which the electrically driven reversing rolling mill has been adopted especially within the last year, is surprising in view of the strongly entrenched position of the steam driven mill. Electric motors have been used for many years on mills running continuously in one direction, but many motor users have felt that the reversing mill could be better handled with the steam engine. There are naturally many characteristics little understood, due to the limited use in this country today.

This paper answers some of the questions which are raised and describes the constructions that have been found desirable.

THE ELECTRICALLY driven reversing mill has been the subject of a number of papers* before the Institute in which the general scheme of operation has been described in detail. Since these papers were presented this type of mill has been considerably developed and a number of installations made. In addition, a great many new mills are being equipped, and within the next year there will be 15 reversing mills in operation in the United States. The great success that has been attained appears to warrant a review of this subject together with a discussion of some of the characteristics of this equipment.

Since the first installations were made and mill engineers have been in a position to personally check the operation and economy of equipment, the steam engine for reversing mills has been comparatively neglected. As an indication of the position that the electrically driven mill has attained, the engineers of one of the large steel companies upon making investigation regarding the type of drive to install for new reversing mills, stated that the electric drive would undoubtedly in the very near future entirely supplant the reversing steam engine except

*Electrically Driven Reversing Mills, by Wilfred Sykes. A. I. E. E. TRANSACTIONS, 1911.

Operation of a Large Electrically Driven Reversing Mill. By Wilfred Sykes, A. I. E. E. TRANSACTIONS, 1912.

Electrification of a Reversing Rolling Mill of the Algoma Steel Co. By B. T. McCormick, A. I. E. E. TRANSACTIONS, 1912.

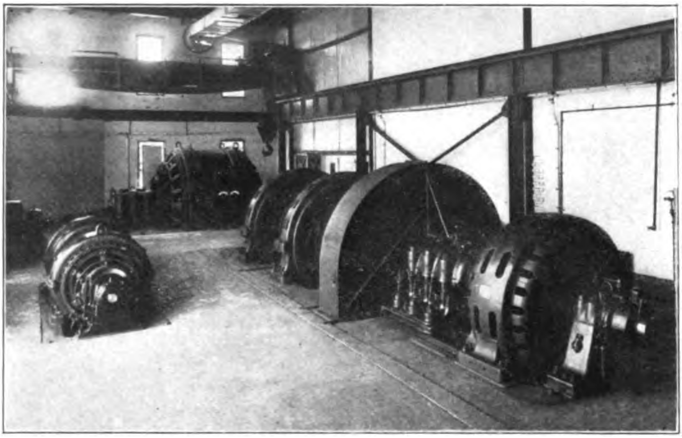
Manuscript of this paper was received April 14, 1916.

in perhaps certain peculiar cases. Practically all the new installations of reversing mills contemplated at present will be electrically driven. Although the electrically driven mill has not so far made the advance in this country that it has in Europe, it is characteristic of American practise to quickly adopt any device which has been demonstrated to suit the American conditions. The reversing mill as developed in this country and as shown by the existing successful installations, differs in many respects from European construction. Special attention has been given to the mechanical construction of the reversing motor and every care has been taken to insure that the machine will stand the much rougher handling which it receives in this country.

As pointed out in one of the papers previously read before the Institute, the reversing plate-mill drive installed at the South Chicago plant of the Illinios Steel Co. was the second drive of this type to be put into operation in the world and it was designed without knowledge of the fact that a similar arrangement was being constructed in Europe. It was a number of years later before a reversing blooming mill was electrified.

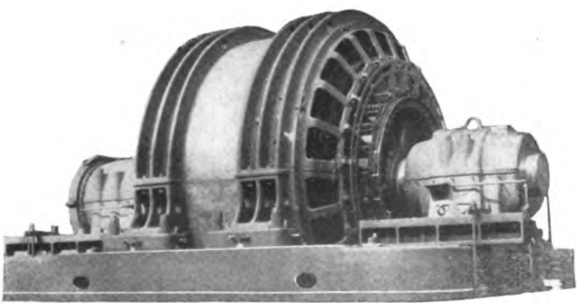
The first successful installation of a reversing blooming mill was that of the Steel Company of Canada at Hamilton, Ont. This installation consists of a double reversing motor capable of developing about 10,000 h.p. maximum, and is supplied with power from a flywheel motor-generator set with two generators. The complete electrical installation is shown in Fig. 1. This mill has been in operation for over three years with very satisfactory results. It is at present working at a rate very considerably in excess of the capacity specified when it was installed. The following are particulars of the mill and driving equipment.

Size of ingot	15 by 17 in.
Weight	4000 lb.
Finished material	4 by 4 in.
Elongation	16
Number of passes	19
Capacity, tons per hour	60
Roll diameter	30 in.
Pinion diameter	34 in.
Speed, full motor field	70 rev. per min.
Speed, weakened motor field	100 rev. per min.
Driven from motor	direct
Number of motors	2
Voltage across each armature	600
Maximum operating torque	900,000 ft-lb.
Maximum motor horse power	10,000
Number of generators	2
Rated power of driving motor of set	1800 h.p.
Weight of flywheel	100,000 lb.
Speed of flywheel set	500 rev. per min.



[SYKES]

FIG. 1—GENERAL VIEW OF FLYWHEEL MOTOR GENERATOR AND REVERSING MOTOR INSTALLED AT THE PLANT OF THE STEEL COMPANY OF CANADA.



[SYKES]

FIG. 2—REVERSING MOTOR BUILT FOR BETHLEHEM STEEL COMPANY ASSEMBLED IN SHOP.

The largest installation at present in operation is that of the Bethlehem Steel Co. which drives the 35-in. blooming mill at the Lehigh Plant. Fig. 2 shows the motors as assembled in the shop before shipment. Both of the above mentioned installa-

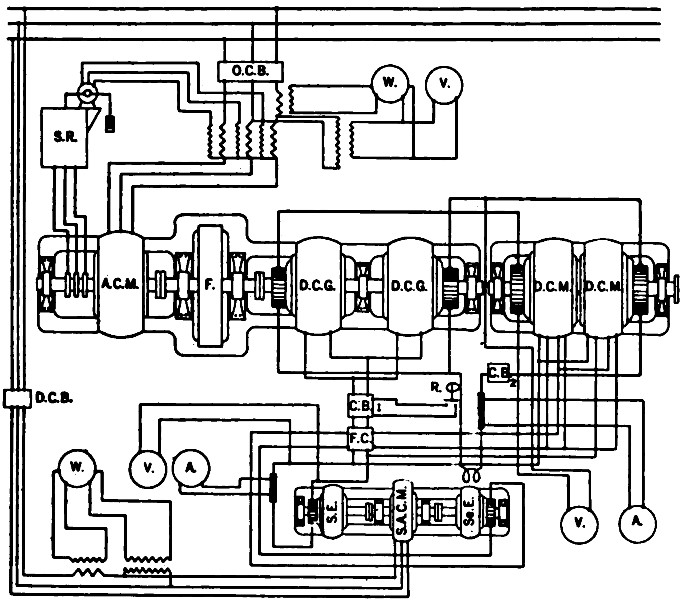


FIG. 3—SCHEMATIC DIAGRAM OF CONNECTIONS OF LARGE REVERSING MILL DRIVE

OCB —oil circuit breaker with no-voltage and overload trip
SR —automatic liquid slip regulator
ACM —alternating-current wound rotor induction motor
DCG —direct-current separately excited generators
DCM —direct-current separately excited roll motors
CB —circuit breakers—1 generator field—2 main circuit
R —relay for operating circuit breaker in generator fields
FC —field controller
F —flywheel
SE —shunt exciter for generator and roll motor fields
SeE —roll motor exciter the field of which is separately excited by the main d-c. circuit
SACM —alternating current squirrel cage induction motor
V —voltmeter
A —ammeter
W —wattmeter

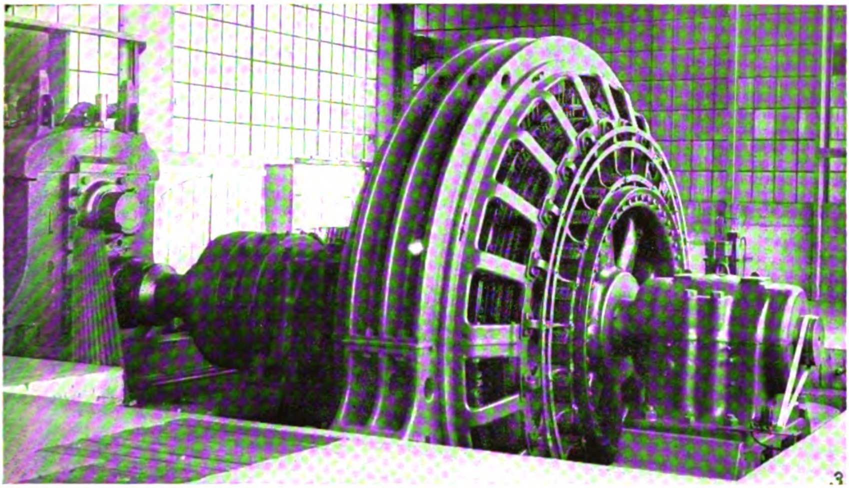
tions have double motors due to the amount of power required. The machines are arranged as shown by diagram, Fig. 3. A somewhat similar drive is installed at the plant of the Central Steel Co., Massillon, O., but a single motor is used for driving the mill, the capacity of the motor being approximately 8000 h.p.

This motor is shown in Fig. 4, which illustrates the machine as installed for driving the mill. Characteristics of these mills are as follows:

	Bethlehem Steel Co.	Central Steel Co.
Size of ingot	19 by 23 in.	18 by 20 in.
Weight	10,000 lb.	5,000 lb.
Finished material	4 by 4 in. up	4 by 4 in. up
Elongation	10–12 av.	Up to 20
Number of passes	17–21	19–21
Capacity, tons per hour	100	60
Roll diameter	30 in.	30 in.
Pinion diameter	35 in.	34 in.
Speed, full motor field	40	50
Speed, weakened motor field	120	120
Driven from motor	direct	direct
Number of motors	2	1
Voltage across each armature	600	700
Maximum operating torque	1,550,000 ft-lb.	750,000 ft-lb.
Maximum motor horse power	12,000	8,000
Number of generators	2	1
Rated power of driving motor of set	2,000 kw.	1,500 kw.
Weight of flywheel	100,000 lb.	60,000 lb.
Speed of flywheel set	375 rev. per min.	375 rev. per min.

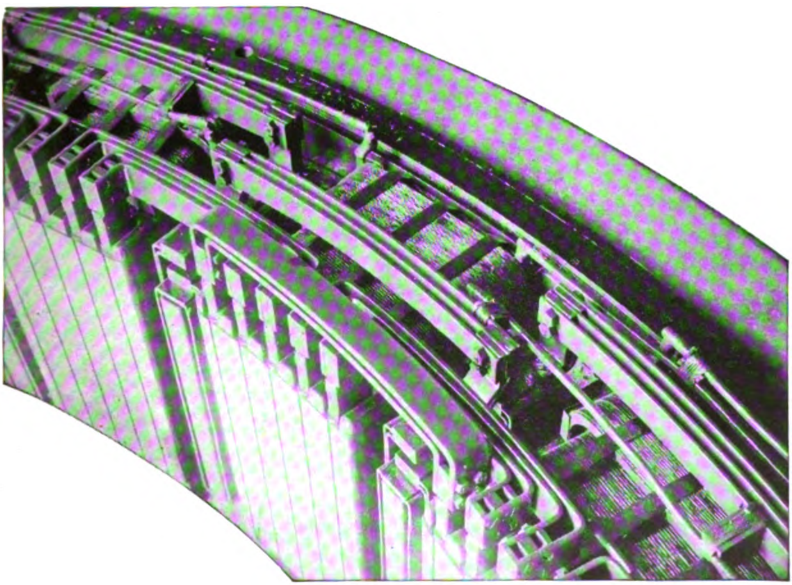
In the recent installations the reversing motor is arranged to have the characteristics of a compound machine. This is obtained indirectly through a series exciter. The current to be handled in the main circuit may be as high as 10,000 amperes, and it is obvious that it would be extremely difficult to reverse the series field each time the motor is reversed, which would be necessary to keep both fields in the same direction. A series exciter is therefore used, the voltage of which is proportional to the current flowing in the main circuit. The armature circuit of the series machine supplies a separate winding of the field of the motor which may be readily reversed when the direction of rotation current is changed. The switches for reversing this field are operated from the same point on the master switch that reverses the field of the generator. The use of a motor with compound characteristics makes the operation of the mill a good deal easier on the mechanical equipment as the drive has more or less "give" to it. At the same time if there is an extreme load due to excessive draft or cold steel, the motor characteristics tend to compensate by automatically increasing the torque available and decreasing the speed.

Although the electrically-driven reversing mill has been practically adopted universally for all new installations there is still some misapprehension as to its operating characteristics.



[SYKES]

FIG. 4—REVERSING MOTOR DRIVING BLOOMING MILL OF CENTRAL STEEL COMPANY



[SYKES]

FIG. 12—COMPENSATING AND COMMUTATING POLE WINDINGS AS USED IN REVERSING MILL MOTORS

It is of course natural that engine builders will fight the development of the electric reversing mill drive as much as possible and the following advantages have been claimed by one of the prominent engine builders:

1 *First Cost.* The first cost of the reversing engine is only a small fraction of the aggregate cost of an electric drive (steam turbines, generators, converter sets, motors, field controls and auxiliaries).

2. *Cost of Operation.* The modern reversing engine uses no more steam to do the work required than an electrical drive.

3. *Energy Saved During Reversal.* In a properly designed engine and mill *all* of the energy required for acceleration early in the pass is utilized at the end of the pass; while with an electric drive, due to the heavy rotating masses, only part is saved.

4. *Low Power Consumption with Partial Load.* High economy is obtained at partial load because a properly designed engine works with cut off. Low pressure control valves prevent all racing and speeding.

5. *Greatest Economy of Time.* A modern reversing engine accelerates in less time than will ever be possible with a motor on account of the smallness of the rotating masses of the reversing engine."

As these are points that can be directly answered from data already available on electrically driven reversing mills in the United States, the points are taken up in the order given.

1. The first cost of an installation does not consist only of the cost of the engine or of the motor driving the mill. In the case of steam drive there are a great many items to be considered which include boiler plant, coal and ash handling facilities, coal storage yards, steam piping, condensing system, water supply for the condensing system, and foundations. In the case of electric drive in addition to the reversing motor there is the flywheel motor-generator set to supply power to it and the generating equipment consisting of power house with its complete equipment, or if power is purchased the only items to be considered are the motor-generator set, reversing motor and the small amount of control apparatus. Many of the items entering into the cost of the drive depend upon the particular layout of the plant. For, instance the whole plant layout might have to be modified so as to enable boilers to be located within a reasonable distance of the steam consuming engines, and this

very often seriously restricts the arrangement of the mills and other units. It may cost a very considerable amount of money to supply water to the engine condensers, which must be used if reasonable economy is desired, whereas in the case of generating station it would naturally be located close to the water supply. This would also be the natural location if blast furnaces are installed, as in this case the boilers would be close to the blast furnaces and the blast furnaces will of course be close to the dock on which the ore is unloaded, if water transportation is used. In any case the blast furnaces would be located close to the water supply which is also desirable for the boilers. It is of course immaterial from the distribution standpoint where the generating equipment is located. This is not so with the steam driven plant due to the length of piping and the consequent losses. The statement that the first cost the reversing engine is only a small fraction of the aggregate cost of an electric drive is certainly not correct as will be shown by the following figures. These figures are based on the actual installation cost and while some of the items would undoubtedly have to be modified to suit different locations, these figures give some idea of relative costs of the equipments.

Cost of Equipment for Driving 40 in. Blooming Mill to Roll 60,000 Tons of Steel per Month, 24 by 24 to 8 by 8 in.

Electric drive with purchased power.	
Complete cost of reversing motor, flywheel motor generator set, exciters and control equipment	$185,000
Foundations, wiring, etc	10,000
Total	$195,000
Electric drive with power generated at plant.	
Complete cost of reversing motor, flywheel motor generator set, exciters, and control equipment	$185,000
Foundations, wiring, etc	10,000
Proportion of power house cost, 2500 kw. at $50 per kw	125,000
Transmission and outside wiring	5,000
Total	$325,000
Steam Drive.	
Compound reversing engine	$125,000
Condenser, exhaust piping, including pumps	25,000
Foundations	10,000
Boilers, 2500 h.p., including stokers, coal and ash handling plant at $30 per h.p.	75,000
Steam piping with covering, valves, etc	15,000
Water tunnel for condenser with discharge 8500 gallons of water per minute	50,000
	$300,000

2. The statement that the modern reversing engine uses no more steam than the electric drive indicates the lack of knowledge of what the electric drive requires. So that there can be no misunderstanding on this point, in Tables I and II are produced the figures from a paper read before the Engineers Society of Western Penna. by Mr. Karl Nibecker giving the results of tests on a reversing engine. This engine is one of the most modern installed in the United States and comparison between it and the electrically driven mill can be justly made. It will be noted

TABLE I.—STEAM CONSUMPTION OF REVERSING STEAM DRIVEN BLOOMING MILL

POUNDS OF STEAM PER TON

No.	Size		Elongations	Lb. steam per ton	Remarks
	Ingot	Bloom			
A	20 by 22 in.	7 by 6 in.	9.04	587	Cold ingot
B	20 " 22 in.	7 " 6 in.	9.04	490	Hot ingot
C	20 " 22 in.	7 " 6 in.	9.04	497	Good rolling
D	20 " 22 in.	7 " 6 in.	9.04	520	New engineer
E	20 " 22 in.	7 " 6 in.	9.04	518	New engineer
F	20 " 22 in.	7 " 6 in.	9.04	575	Bad rolling
G	20 " 22 in.	7¾ " 3½ in.	15.1	767	New engineer.
H	20 " 22 in.	7¾ " 3½ in.	15.1	610	Good manipulation
I	20 " 22 in.	11¾ " 3 in.	10.75	694	New engineer
J	20 " 22 in.	11¾ " 3 in.	10.75	625	Good manipulation
K	18 " 32 in.	23¾ " 4½ in.	5.13	522	Good rolling-cold
L	18 " 32 in.	23¾ " 4½ in.	5.13	423	Good rolling-hot
M	19 " 46 in.	36½ " 4¾ in.	4.63	356	Bad rolling
N	19 " 46 in.	36½ " 4¾ in.	4.63	292	Good rolling

TABLE II.—STEAM CONSUMPTION OF REVERSING STEAM DRIVEN BLOOMING MILL

Size		Number of elongations	Lb. steam per ton	Lb. steam per ton at	
Ingot	Bloom			5-Elong.	9-Elong.
20 by 22 in.	11¾ by 3 in.	11.5	643	444	591
20 " 22 in.	7¾ " 3½ in.	15.0	600	375	505
20 " 22 in.	7 " 6 in.	9.0	495	350	495
18 " 32 in.	23¾ " 4½ in.	5.0	420	420	....
16 " 32 in.	29 " 5 in.	3.25	280	...	....
19 " 46 in.	36½ " 4¾ in.	4.75	300	...	....
18 " 32 in.	23½ " 3 in.	7.5	410	256	....

that these are tests of single ingots, but Table I shows the results of a series of six ingots rolled from the same size bloom from which a fair average can be obtained. Table III gives the results of tests made upon electrically driven reversing mills which are shown graphically in Fig. 5. These figures are not the results

TABLE III.
ELECTRICALLY DRIVEN REVERSING MILL.

Ingot	Bloom	Elongation	h.p-hr. per ton.	Remarks
18 in. round	7¾ by 7¾ in.	4.66	11.4	High carbon
18 by 20 in.	3 " 8 in.	12.2	23	" "
18 " 20 in.	2 " 16 in.	9.2	19.4	Soft steel
18 " 20 in.	4 " 4 in.	18.5	26	
17 " 15 in.	4 " 4 in.	16.	24	
20 " 20 in.	5 " 5 in.	16.	25.5	
20 " 20 in.	8 " 8 in.	6.25	17.	

of tests of individual ingots but are based upon the power consumption of a large number of ingots rolled during the regular operation of the mill and they do not in any way represent figures made under ideal test conditions. They have been obtained by reading the watt-hour meter in the line supplying power to the reversing mill equipment including all losses and

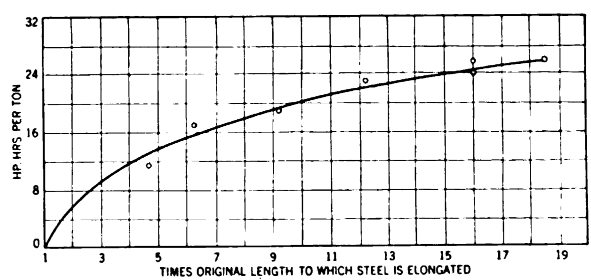


FIG. 5—CURVE SHOWING RELATIONS BETWEEN INPUT TO ELECTRIC DRIVEN REVERSING MILL AND ELONGATION OF STEEL ROLLED

represent the total power required to drive the mill. Fig. 6 shows the steam consumption of a 5000-kw. turbine, which is a common size in steel mills, operating under the same steam conditions as the steam-driven reversing mill. These steam conditions are not altogether ideal for a turbine as a higher pressure and superheat might be used, in which case still lower

steam consumption and better thermal efficiencies would be obtained. This curve of steam consumption includes the power necessary to operate the condenser circulating water pump and the air pump. Under normal operating conditions the turbine would run at 70 per cent of load and taking the steam consumption at this point, we find that one h.p-hr. can be generated for 13.6 lb. of steam. From the power requirement the total steam consumption can be calculated and it will be seen that this does not amount to more than from 50 per cent to 60 per cent of the best engines installed in the United States to date.

3. The question of saving accelerating energy is one that is given a good deal of thought by the engine builders as there is no way of storing it in the engine. The characteristics of the motor and engine are entirely different. It is true that if a mill is operated in an ideal manner the metal will leave the rolls at practically zero speed so that all the energy stored in the rotating

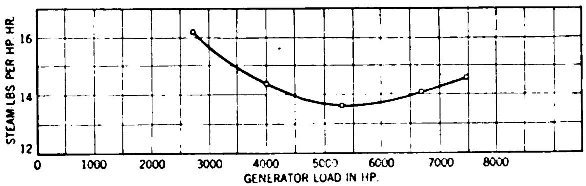


FIG. 6—STEAM CONSUMPTION OF 5000 KW TURBINE, 150 LBS. STEAM PRESSURE, 28-IN. VACUUM

parts will have been returned to the mill and usefully consumed. Mills, however, are not operated in this way and neither the electric drive or the engine drive is operated in an ideal manner. Mills are handled by workmen and not by designers, and production is the object arrived at. The workmen are not interested nor do I believe it is possible to interest them, in the best conditions for obtaining low power consumption. This is a condition that must be reckoned with, and if possible the design of the equipment should be such that the power consumption cannot be affected materially by unskillful operation.

Due to the fact that the speed of the reversing motor is proportional to the throw of the controller handle and does not vary appreciably with the load, ideal conditions can be more nearly approached than with a steam engine. In the case of steam drive, it is quite common for the engine to race after the metal has left the rolls, especially if the draft has been a

heavy one, when there may be a large volume of steam in the cylinders which is not expanded, and which accelerates the engine parts. The engine must then be stopped and energy is required to do it. Fig. 7 shows the speed curve of a reversing engine taken from a recent test. It will be seen that in quite a number of cases the engine has raced after the metal leaves the rolls. For comparison a similar speed curve is reproduced of an electrically driven mill taken from the motor at the plant

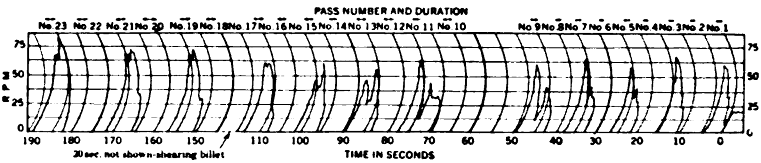


FIG. 7—SPEED CURVE OF REVERSING ENGINE. (*Note:* ONLY ALTERNATE PASSES SHOWN TO OBTAIN LARGE DEFLECTION ON RECORDING INSTRUMENT.)

of the Central Steel Co. In the case of electric drive, the motor is stopped by reversing its function and making it act as a generator. This is a natural characteristic of the equipment and enables the braking to be done very rapidly and also economically, as the energy stored in the rotating parts is returned to the flywheel of the set. The losses are only those due to the resistance of the windings. Whatever energy might therefore be lost due to the fact that the mill is not operated in an ideal

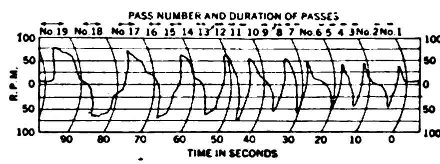


FIG. 8—SPEED CURVE OF REVERSING MOTOR DRIVING MILL

manner is returned to the flywheel and is available for the next pass. The whole point, however, is of little importance as it shows up in the relative power consumption of the two methods of drive which after all is the only criterion as to which is the better system to use.

4. With electrically driven mill the economy of course falls off somewhat as the output is reduced due to the continuous windage and friction losses of the flywheel motor-generator

set which are independent of the load on the machine. Outside of these losses it makes practically no difference whether one or 30 ingots are rolled per hour as far as the unit power consumption is concerned. In other words, the net power, (leaving out the constant losses) per ton of steel is practically independent of the quantity rolled. A somewhat similar condition exists with the steam engine inasmuch as it has certain constant losses due to leakage, piping and auxiliary power. However, outside of these losses the steam consumption will not be constant per unit of work done as the expansion conditions vary.

TABLE IV.
TIME STUDY OF REVERSING ENGINE

Pass No.	Time of entering pass-sec.	Manipulation
1	0.	
2	3.5	
3	9.7	Turn
4	13.	
5	17.2	
6	20.8	
7	27.2	Turn
8	31.8	
9	37.0	Turn
10	42.0	
11	50.0	Turn
12	55.0	
13	62.0	Turn
14	67.7	
15	75.8	Turn
Leaving press	79.3	

5. The question of the time required for operation is liable to be clouded very much by conditions that have nothing whatever to do with the time required for rolling the metal. It is undoubtedly true that the steam engine can reach certain given speeds quicker than the reversing motor. At the same time it does not necessarily follow that the reversing engine will roll any greater amount of metal than the reversing motor. It depends upon many other conditions such as the way the metal is handled on the tables, the maximum speed reached, and also time lost in the manipulation of the driving unit. Table IV shows the results of a time study brought out in a discussion

of the paper already referred to. Table V shows the results of similar figures taken from the reversing motor on the Central Steel Co. plant at Massillon, O. It will be seen that the time of entering the 15th pass in the case of the steam-driven mill was 75.8 seconds from the beginning of rolling and in the case of the motor driven mill 59.8 seconds. While it is not claimed that these figures show the advantages of one over the other system of drive yet they are sufficient to indicate that in practise the reversing motor will operate just as quick, if not quicker

TABLE V.
TIME STUDY OF REVERSING MOTOR

Pass No.	Duration of pass	Interval after pass	Time of entering pass integrated	Rev. per min. at entrance of ingot	Maximum rev. per min.	Rev. per min. as ingot leaves rolls
1	1.5	1.7	0	15.5	39	26.5
2	1.2	5.	3.2	36	47	31 *
3	1.7	1.6	9.4	12.5	47	28
4	1.4	1.5	12.7	23	48	27.5
5	• 1.7	1.4	15.6	7.8	44	20
6	1.7	5.5	18.8	23.5	55	31 *
7	2.0	1.2	26	11	50	18.5
8	2.0	0.6	29.2	23.5	62	12.5
9	2.5	1.4	31.8	15.5	56	31
10	2.2	3.7	35.7	23.5	59	31 *
11	2.5	0.8	41.4	18.5	55	14
12	2.6	1.2	44.7	23.5	78	31
13	2.9	2.0	48.5	23.5	62	34
14	2.6	3.8	53.4	28	67	51 *
15	2.8	2.0	59.8	7.8	64	31
16	3.0	4.2	64.6	15.5	76	55 *
17	5.0	4.2	71.8	23.5	74	31
18	5.0	5.0	81	23.5	70	62 *
19	6.5	2.5	91	22	80	12.5

* Piece manipulated.
Rolling 18 by 20 in. Ingot to 3 by 8 in. sheet bar blooms.

than the engine. Due to the ease of control of the motor drive is a good deal lighter on the operator and consequently he is able to continue running the mill at a maximum capacity with less fatigue than in the case of a steam-driven mill.

The design of the reversing motors and the generators supplying them with power presents many problems not encountered with ordinary direct-current machines. As the success of this type of mill depends upon the machines meeting the severe operating conditions without injury or deterioration, a brief review of the principal characteristics may be of interest.

There is no other class of service which might be properly compared with the requirements of a large reversing mill. The heavy torques, the sudden peak loads, and the quick reversals all call for apparatus of substantial mechanical design, and flexibility in electrical characteristics. The exchange of energy between the driving motor and the generator undergoes changes at a very rapid rate. In fact, the driving motor must perform the functions of a generator as will as that of a motor, and the supply generator may at one instant be furnishing current to the driving motor, and at the next instant it may be receiving electrical energy from the driving motor, and delivering mechanical energy to the flywheel. For example, the equipment at Bethlehem, which consists of two 600-volt motor armatures supplied by two 600-volt generator armatures all connected in series, may at one instant show a swing of 10,000 amperes, and at the next instant the swing may be of an equal value in the opposite direction. There must be rapid adjustments of flux conditions in both motors and generators in order to meet these reversals without showing harmful sparking at the brushes, and as the swings which occur many times a minute represent over-loads of 200 to 300 per cent, the design of the direct current machines must be suited to these over-loads, both in current carrying capacity and in flux conditions. Especially must the machines be designed for good commutation. This cannot be obtained at such overloads without making liberal allowances for the commutating flux, as the ratio which the commutating flux bears to the load must not be disturbed by leakage conditions, even at the overloads. This feature is more readily obtained by compensating the armature reactance to which further reference will be made, and this type of construction is of greatest importance, to successful results.

The choice of voltage per commutator and the use of two armatures, the commutators of which are connected in series for large powers, is deserving of a careful analysis, and this voltage should be selected with due consideration of the motor, the generator and the auxiliary apparatus. The following arguments are to show that, other things equal, it is desirable to adopt a relatively high voltage; viz. 600 volts and by series connection, alternating a motor with generator, derive all the benefits of 1200 volts.

The electrical equipment of a reversing rolling mill includes both the d-c. generator as well as the d-c. motor, and the gen-

erator does not furnish power to any other apparatus except the roll mill motor. The *voltage* should be of such a value as will give the best balanced equipments and the choice of voltage becomes a very important factor as the design of the entire equipment may be said to depend in a great measure upon the voltage selected.

The use of 250 volts has been common practise in rolling mills and it is natural that this voltage should be considered. However, for large capacities, there are many objections to so low a voltage, among which may be mentioned heavy currents, large commutators, larger machines, lower efficiencies, increased cost of auxiliary apparatus, higher maintenance charges and increased mechanical difficulties.

The magnitude of the current becomes a factor when the power required on peak loads may reach 15,000 to 20,000 h.p. and not only are the connections, cables and switching apparatus expensive, but the losses in these parts are roughly proportional to the currents. The approximate cost of these parts will vary inversely as the voltage.

The size of commutators and the number of brushes will be a direct function of the current and it is desirable to keep down the size of the commutators from at least three points of view —mechanical difficulties of construction, over-all length and cost. No part of a direct-current machine is so difficult to construct as is the commutator, and for this reason the construction of commutators has received, and will continue to receive the most careful consideration from both the design and the manufacturing points of view. So all important is the commutator and the commutation that when these are right, there is seldom any cause for complaint. Increased voltage not only reduces commutator length, but insures less overall length—an extremely desirable factor.

The efficiency of the equipment as a whole will be higher with increase of voltage within certain limits, as in such installations the peak loads are relatively high as compared with the average or mean load.

The commutating conditions of the generator is one of the items which must be carefully considered in the selection of voltage, especially as economies can be effected by operating the flywheel set at a reasonably high speed. It is desired to consider whether a generator can be designed better for one voltage than for another, and what is a safe operating speed for

a generator of a given output and voltage. With a view of setting forth the relations of kilowatt capacity and speeds, the writer has chosen familiar voltages of 125, 250, 600, 1200 and 2500 volts, and has plotted a curve for each one of these voltages. These curves are shown in Fig. 9. There are certain fairly well established relations and limits in direct-current machines, which lead to limits of output. However, it is not so much these limits that we would direct attention to at the present moment, but the relation of possible outputs of different voltages. It will be observed that at 600 volts the possible outputs are greater than at either 250 volts or 1200 volts. This means that with the same degree of safety it is possible to make a larger 600-volt generator than a 250-volt or 1200-volt generator, for a given

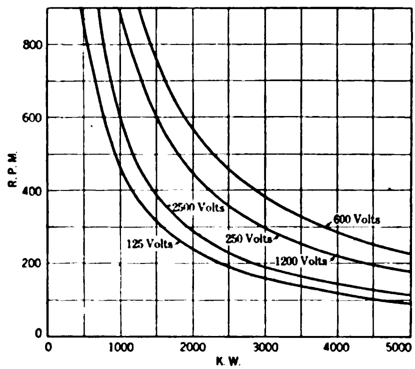


FIG. 9—CURVE SHOWING THE LIMITS WITHIN WHICH DIRECT-CURRENT GENERATORS CAN BE BUILT

speed. This relation applies at all speeds. It will be observed that the product of kilowatt output and rev. per min. is approximately a constant for a given voltage. This relation is frequently lost sight of in considering the possibilities of machines for large output, at high speed. The basis on which these curves have been made up depends upon setting certain limits. These limits are not definitely fixed quantities, as each designer will set limits depending upon the experience which he has had with various machines. The relation of these limits will in a measure determine which curve will be highest, and some of these limits are entirely independent of each other. The limits which determine the possibilities of high-voltage machines are entirely different from those which determine the possibilities in low-voltage machines. Curves could be drawn for all voltages in

a similar manner as these have been determined, but the more usual voltages are used for the sake of illustration, and they serve the purpose of showing the desirability of using a relatively high voltage for roll mill motors, such as we are considering.

As these curves represent limits it is of course understood that most machines will fall under them and the extent to which a machine falls within the curve will represent in a measure the ease with which that machine can be designed. We would emphasize the fact that the minimum cost for a given rating does not necessarily call for the highest possible speed, and the present day tendency of going to extreme speeds should be discouraged.

From these curves we deduce that 600 volts is a desirable selection per commutator for the generators and it is also evident that 1200 volts per commutator would be possible. A voltage

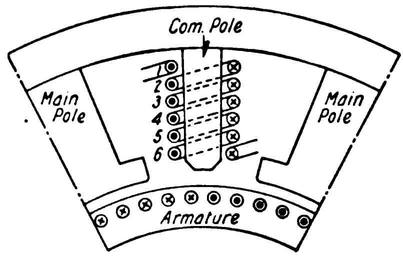


Fig. 10—Commutating Pole Winding

of 600 per commutator has proven well suited for the motor, as a lower voltage would lead to relatively large armature diameter. A very much higher voltage would require few poles with correspondingly heavy rotors, and either of the conditions is undesirable as low inertia effect is important.

Type of Winding

To obtain the best operation under heavy peak loads, which are subject to very rapid changes, for example, three times normal load, reversing at the rate of 30 times a minute, it is not only desirable, but it is necessary to neutralize to the fullest extent the distorting effects of the currents in the armature winding. The method of obtaining this result is to slot the pole face, and secure in these slots a bar winding which is connected in series with the armature, and making a number of conductors in the pole face just sufficient to neutralize the armature conductors

covered by the pole face. The excess winding necessary to produce a commutating flux is concentrated on the commutating poles, located midway between the main poles. The difference between the compensating winding and the interpole winding is illustrated in Figs. 10 and 11, which show the same number of conductors in both cases, but the conductors are shifted in position. In the plain commutating pole machine, having all the commutating winding located on the commutating pole, the conductors are as shown in Fig. 10, whereas in the compensating pole machine, which has part of the compensating winding located in the main pole face and the balance located on the commutating pole, the conductors are as shown in Fig. 11. By locating in the pole face the ampere conductors which neutralize the armature reaction under the pole face, the distortion of the flux at the main pole face is prevente has a beneficia

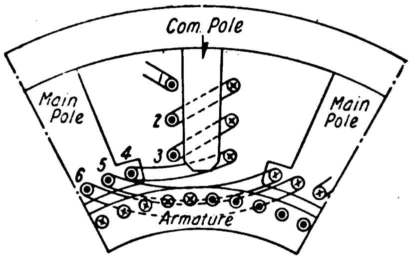


FIG. 11—COMMUTATING POLE AND COMPENSATING WINDING

effect in two ways. First, it prevents under sudden changes of load, a sweeping across the pole face of the main flux under the pole, and it prevents a distortion of the main flux which is a very important consideration, as this lowers the maximum voltage between adjacent commutator bars, which would otherwise obtain. As it is the maximum voltage between commutator bars, rather than the average voltage, which determines the design, the importance of this type of construction becomes evident for this class of service. Another very important consideration in this arrangement of the compensating winding is that the leakage from the commutating pole is very much less than would be the case if all of the windings were concentrated on the interpole. This fact permits the carrying of heavier overloads, and it is the overload capacity which determines to a great extent the suitability of machines for this class of service. It is evident that the leakage is very much reduced, when one

considers that the leakage is mainly between the main pole tip and the interpole, and that the magnetomotive force producing this leakage is made very much less by locating a large proportion of the ampere conductors in the main pole face.

This construction permits the operations of the machines through a wide range of voltage; in other words, the stability of the main flux is insured without regard to the strength of the main field winding. This is an important factor in the general scheme of control, as the speed of the motor and the direction of rotation of the motor depend upon the generator voltage and upon the field strength of the motor. These two factors must be susceptible to rapid changes and wide variations in order to effect the desired result.

In referring to the relative merits of commutating pole machines, versus machines with compensating winding, for this class of service, attention may be called to the fact that compensating windings are difficult of construction, in machines having very large current, as there is a limit to the desirable physical dimensions of a single pole face conductor. With heavy current machines, a suitable arrangement of compensating conductors is often quite a problem in a specific design. The most desirable arrangement is to have all compensating conductors connected in series, and the possibility of such an arrangement is limited by the capacity and voltage of the machine, and here again there is a decided advantage in not having the voltage too low, for large power capacities. For example, a single conductor having a cross section of more than two sq. in., is seldom used in the pole face winding. Assuming a current density of 1500 amperes, a single conductor, with all conductors in series, can be used on a 3000 ampere machine, which, at 600 volts, represents an 1800-kw. capacity. For larger current capacities, it is necessary to connect the conductors in parallel, and frequently the circuits are in parallel. In such cases, great care must be exercised in the building of the machines so as to have good joints, in order to insure the proper division of the current.

Generally speaking, the compensating winding of large capacity machines consists of a relatively small number of conductors, and simpler, better mechanical arrangements can be effected than are possible with smaller capacity machines. It is also desirable to design the compensating winding and the commutating pole winding so that no shunts will be necessary. This can readily be accomplished as it is possible to calculate very

closely the required ampere conductors, for compensating the armature reaction and furnishing the necessary excitation for the commutating pole. By avoiding shunts, one is insured of the simultaneous change of current in the compensating winding and the armature winding.

Field Windings

The type of field winding used on roll mill machines should be very simple, and such as not to be easily damaged. If a low voltage is used for excitation of the d-c. generator and d-c. motor field coils, these coils can be made of copper strap winding with a layer of asbestos between turns, and the bare edges exposed to the air. Such coils are almost indestructible by heat. Strap wound field coils arranged in two or more concentric sections insure a natural and easy ventilation.

Insulation

As this type of machinery is exposed to mill dust, and as this dust is likely to contain a large percentage of conducting material it is advisable in the design to embody more liberal creepage distances than are necessary for ordinary service. In order to combat, to a certain extent, the bad effects of dust, the armatures may be given a finish by rolling them in varnish and baking them. This produces an insulating film over all parts, and fills all the pores and small crevices in the insulation, and insures a slick finish which will shed the dust.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

MOTOR EQUIPMENTS FOR THE RECOVERY OF PETROLEUM

BY W. G. TAYLOR

ABSTRACT OF PAPER

The work of drilling, pumping and cleaning oil wells is very successfully handled by slip-ring induction motors. With the cable-tool method of drilling a special arrangement of controllers and resistance is used to obtain the required fine speed control. Similar motors are used for both this and the hydraulic rotary method.

Pumping and cleaning, which includes 'pulling' the rods and tubing, are in most cases all performed by the same motor which may be a 'Y-Delta' or a two-speed machine, depending upon operating conditions. Both of these motors are double-rated, the low rating being used for pumping and the other for pulling and cleaning. High efficiency is essential on the pumping duty and high torque for the heavy work of pulling and cleaning the well. For both types of motors special control features are used to properly protect the equipment as well as to make it most convenient for the operator. For wells pumped by jack-rigs, a portable hoist is employed to pull rods and tubing.

This paper presents data covering the horse power requirements and kilowatt-hour consumption for the various operations in drilling and maintaining producing oil wells.

THE GRADUAL decline in production which is characteristic of all oil fields as well as the great losses sustained with the usual methods of steam operation are the factors which generally furnish an incentive to the producing company to electrify its wells. The economy thus gained often gives the wells a longer lease of life, as it enables them to be pumped at a profit at a lower daily production than would otherwise be possible. In most cases economy is only one of the several advantages of motor drive which are taken into consideration, these including greater reliability, simpler and more accurate speed control, steadier speed, greater safety and lower insurance rates than with other types of motive power. These advantages on any motor application are too well known to warrant more than incidental mention.

The choice between alternating and direct current is generally determined by the available power supply and for this reason

Manuscript of this paper was received May 4, 1916.

Induction motors are used on nearly all electrically operated wells. Several isolated generating plants are in operation which were installed for the purpose of carrying an oil well motor load and which were designed for alternating current because of the inherent superiority for this service of an induction motor over a direct-current machine. Although the latter may at first appear to be a more advantageous type of motor on account of the speed variation obtainable by field control without material reduction in efficiency, yet when it is taken into consideration that oil well motors must often carry sudden and severe overloads and be frequently reversed at full speed, and are subjected to much abusive handling by unskilled operators, the overload limitations of a direct-current motor prove to be a severe handicap. A more complex control is necessary to protect the motor, and if this is not provided the depreciation of the commutator is rapid on the heavy duty.

There is a large number of varied operations which oil well motors are called upon to perform, and these fall naturally into three groups; drilling, pumping and cleaning. The process of drilling a well includes the operations of handling the drilling tools and the casing with which the hole is lined, and of removing the drillings by bailing or hydraulic flushing. The work of pumping includes such operations as are occasionally necessary to free the pump and valves from sand. The cleaning of a well is a process which varies with the conditions encountered. It is always necessary, however, to pull out the rods and tubing, which is known as 'pulling' the well. The accumulated sand and sediment are then removed by bailing or hydraulic washing, and may first require loosening up with a light 'string' of drilling tools. Swabbing is sometimes done to improve the flow of oil.

The most logical method of applying motors to these operations is to use a different machine for each of the three groups, as this not only involves the least complication in design, but also requires the minimum investment by the oil company, consistent with efficient operation. It has, however, been found more practical in most cases to use one motor for the drilling process and another for all the work involved in pumping, pulling and cleaning the wells.

Drilling

The two methods of drilling which are in general use in the United States are the standard or cable-tool method, and the

hydraulic rotary method. The former employs a walking-beam from the end of which a heavy stem and bit are suspended by a steel wire or manila rope. These churn the hole by the up-and-

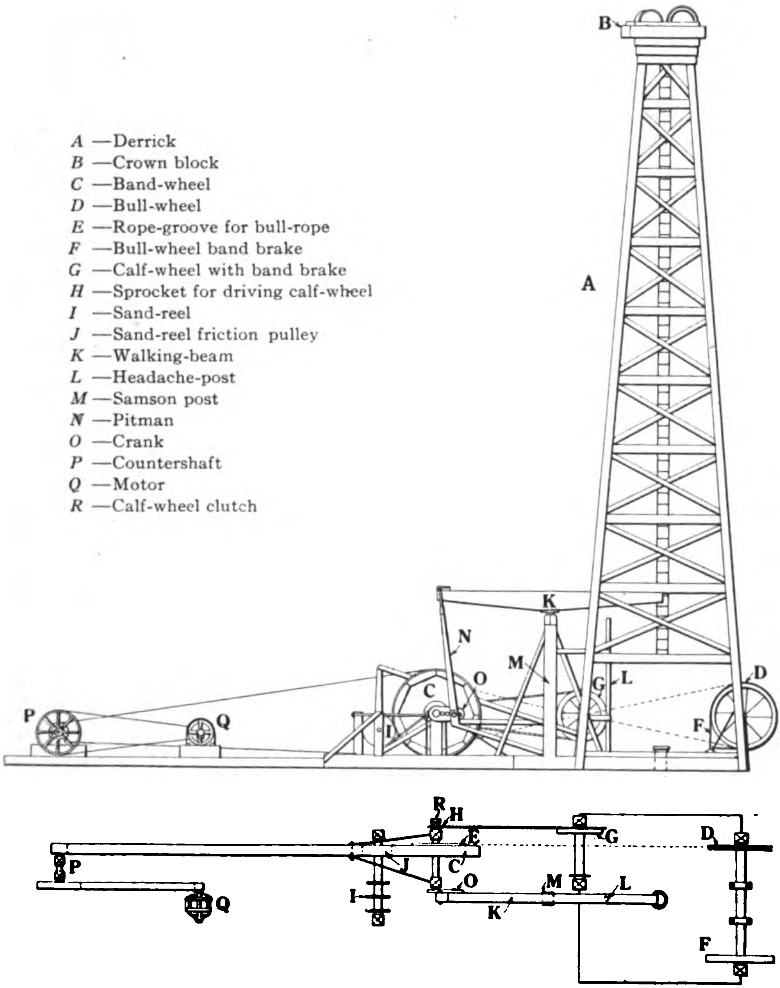


FIG. 1—ELEVATION AND PLAN OF MOTOR-DRIVEN STANDARD CALIFORNIA OIL WELL RIG

down motion imparted by the beam, the strata thus being penetrated by percussion. The drillings are mixed with water in the hole and are removed at intervals by a 'sand-pump' or bailer. As the hole deepens, iron or steel casing is inserted in approxi-

mately 20 foot lengths, screwed together, but may not be used where there is no danger of caving.

The arrangement of the standard motor-operated drilling rig used in the California fields is illustrated in Fig. 1. For actual drilling work the drilling line is suspended from the end of the walking-beam, but the hoisting of the tools is done by the bull-wheel, rope-driven from the band-wheel, with the walking-beam disconnected from the crank. The drilling line is wound on the bull-wheel shaft and passes over a sheave on the crown block. Casing is handled in a similar manner by the calf-wheel, with the addition of a block and tackle having from seven to nine lines. The bailer, which is a long tube with a check valve at the lower end, is hoisted by a separate line wound on the sand-reel, the latter being run from the band-wheel by friction drive. On rigs

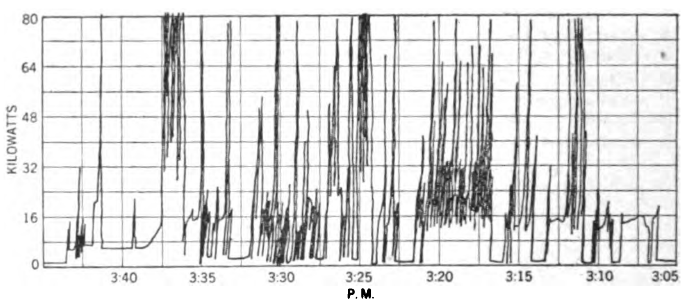


FIG. 2—GRAPHIC RECORD OF POWER REQUIRED FOR "SPUDDING IN" CASING IN A CALIFORNIA OIL WELL

not having a sand-reel the bull-wheel is employed for this purpose.

The heaviest work encountered by the drilling motor is the manipulation of the casing. It is frequently necessary to repeatedly raise and lower a string of casing a few feet for long periods in order to relieve the friction caused by pressure of the surrounding strata, and thus work a clear passage. This is known as 'spudding in' the casing. It requires continued reversing of the motor under heavy load, and is very well illustrated by the graphic record shown in Fig. 2, which was made on a 50-h.p. equipment. It is important that the motor should have ample margin in torque to accomplish this without overheating or stalling, as failure to free the string of casing compels the operator to continue with a smaller diameter. Occurrences of this

kind would result in the minimum diameter being reached at too shallow a depth and thus render it impossible to continue drilling to the oil sand.

The other drilling operations are lighter work for the motor

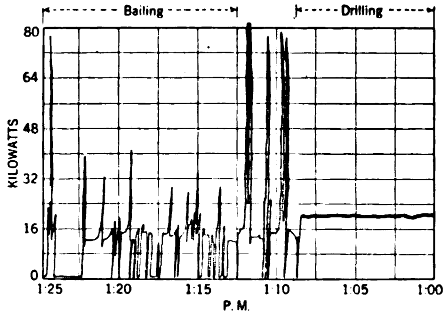


FIG. 3—GRAPHIC RECORD OF POWER REQUIRED FOR DRILLING AND BAILING WORK IN A CALIFORNIA OIL WELL

as will be seen by a comparison of Figs. 2 and 3. The power demand from the motor to merely swing the tools during actual drilling by the cable-tool method is fairly steady, as Fig. 3 shows, but it is interesting to note that this demand becomes less as the well grows deeper. Fig. 4, which represents this

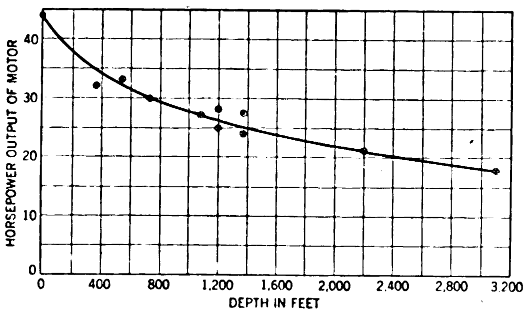


FIG. 4—HORSE POWER REQUIRED FOR SWINGING STANDARD CABLE TOOLS IN DRILLING A 3100-FT. OIL WELL IN WEST VIRGINIA

fact, shows a curve plotted from readings taken during the various stages of drilling a 3100-ft. well. The point may be explained by the facts that as the well grows deeper the drilling tools used are smaller in diameter and lighter in weight, and a larger amount of water is usually carried in the hole.

After a well has reached a depth of 300 or 400 ft., the amount of energy required per hundred feet for all drilling operations by the standard method increases with the depth of the well. Although it has already been pointed out that the power necessary to swing the tools grows less, on the other hand the length of time required for bailing increases in proportion to the depth, with little or no reduction in horse power, and the dash-pot action in pulling out the bailer becomes greater due to the larger amount of fluid carried in the well. It is also usually necessary to work the casing more frequently as the depth increases, in order to prevent it from 'freezing' or sticking. Both of these conditions cause a considerable increase in energy consumption. Furthermore, progress becomes slower as the well deepens. Therefore considering all of these points, it is apparent that the kw-hr. consumption will increase more rapidly than in direct proportion to the depth, and actual results plotted in Fig. 5 for a 2060-ft. well indicate that it varies approximately as the square of the depth, barring accidents and extensive jobs of 'fishing' for lost rope, tools or damaged casing. The individual points also plotted in Fig. 5 represent the total power consumption recorded in drilling other wells of various depths. They check as closely as could be expected with the record for the 2060-ft. well at a corresponding depth. Under the usual conditions encountered, and without any great amount of bad luck in the drilling work, the average daily power consumption when the motor is in use, is about 230 kw-hrs., but it will vary on different days from approximately 135 to 400 kw-hr., depending upon what class of work is being done.

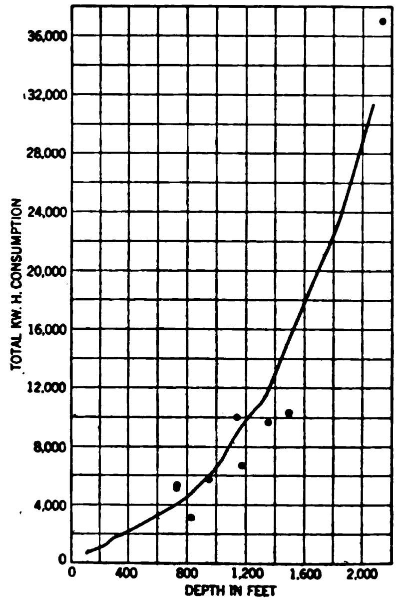


FIG. 5—CURVE OF TOTAL POWER CONSUMPTION COVERING ALL OPERATIONS IN DRILLING A 2060-FT. OIL WELL BY THE STANDARD CABLE-TOOL METHOD. THE INDIVIDUAL POINTS PLOTTED ARE THE TOTAL RECORDED KW-HR. ON VARIOUS OTHER WELLS

The most successful drilling motors now used in American oil fields are of the slip-ring induction type with secondary resistance control arranged for reversing duty. A capacity of 50 h.p. is usually sufficient for wells not exceeding 2500 ft. in depth, though cases have occurred where 75 h.p. was necessary on wells from 2000 to 2500 ft. in depth, as well as on the deeper ones. The belted arrangement with a countershaft has proved the best, as the severe service has rapidly put out of commission the various types of gear drive which have been tried.

In the cable-tool method of drilling, the beam must overspeed and allow a relatively free drop of the tools on the down stroke to obtain the most effective blow; the motor to accomplish

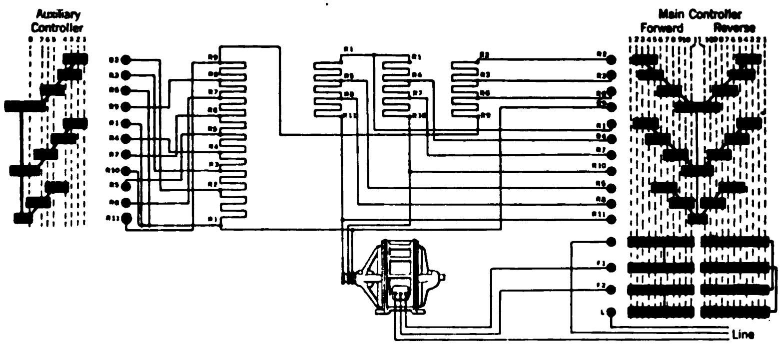


FIG. 6—CONNECTIONS FOR MOTOR EQUIPMENT FOR STANDARD CABLE-TOOL DRILLING

this must therefore slow down on the up stroke and speed up on the down stroke. This is quite successfully accomplished by so proportioning the pulleys that the motor will have some secondary resistance in circuit when running at the correct drilling speed. There is also required a very fine adjustment of speed to make the movement of the beam accord with the natural period of vibration of the drilling line due to its elasticity. Failure to obtain the exact speed results in deadening the movement of the bit and may strain the line and rig dangerously. A suitably designed liquid rheostat would be an ideal method of control if it received the necessary attention and a good quality of water, but unfortunately neither of these can be given it under the usual conditions in the oil fields and so drum controllers have been adopted, connected as shown in Fig. 6. The main

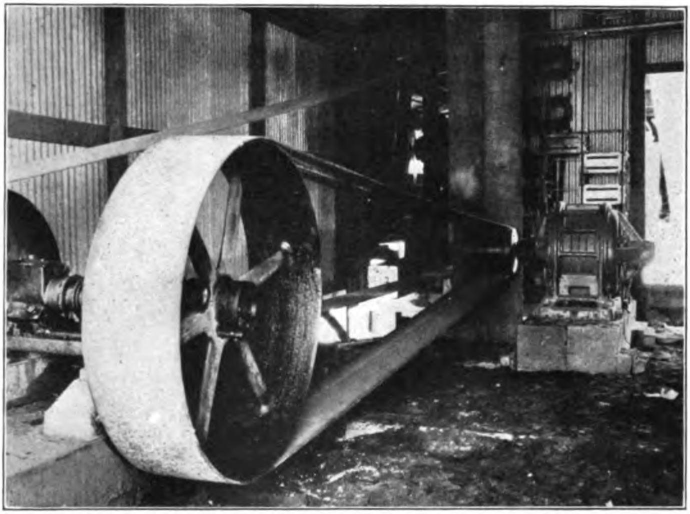
controller gives a coarse variation of speed and reverses the motor, and the auxiliary controller provides a means of obtaining fine speed control between the points on the main controller for either direction of rotation. These controllers are each operated by wire ropes extending to the headache-post in the derrick, the arrangement in this respect being similar to the method of throttle control employed with engine-driven rigs. A complete installation is shown in Fig. 7.

Drilling by the rotary method is accomplished by boring rather than by churning the hole. The drilling bit is supported at the lower end of a column of pipe which is held and rotated by a turntable. The latter is driven through a series of chains and gears. A hoisting drum, which is clutched in when desired, is also provided for handling the drilling stem and casing. The drillings are washed out by a stream of thin mud circulated by the 'slush-pump' down through the rotating column of pipe and up outside of it, thus causing the pipe to turn more easily and preventing caving by plastering the sides of the hole with mud. Only a few wells have so far been drilled by this method with motor drive, but excellent results were obtained with the same type of motor as is used for the cable-tool method. A fairly close speed adjustment is needed to operate the bit at the most effective cutting speed, inasmuch as the latter varies with the nature of the strata encountered.

Pumping, Pulling and Cleaning

Pumping is accomplished by means of a deep-well pump of the plunger type which is lowered on the end of a string of tubing to a sufficient depth to insure ample submersion. The plunger is operated by jointed iron or wooden rods extending down within the tubing and attached to the end of the walking-beam or to a pumping-jack operated from a central power-head. The flow of oil through the tubing to the surface is governed by suitable check valves in the barrel and plunger of the pump.

The rods and tubing must be frequently removed to clean out the well or to replace broken or worn parts, and the bull-wheel is then employed except where the use of pumping-jacks makes a portable hoist necessary. Rods are pulled with a single line, but a block and tackle with two or three lines is necessary for the tubing. Both are removed in lengths approximately 60 ft. long which usually consist of three 20 ft. sections screwed together. Bailing, light redrilling, washing or swabbing may be employed in the process of cleaning.



[TAYLOR]

FIG. 7—A 50-H.P. DRILLING MOTOR OPERATING CABLE-TOOLS ON A STANDARD CALIFORNIA RIG

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FIG. 9—TWO-SPEED 25/8-H.P. 1200/600-REV. PER MIN. THREE-PHASE, 60-CYCLE, 440-VOLT OIL WELL MOTOR FOR PUMPING, PULLING AND CLEANING WELLS OF MODERATE DEPTH

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There is no apparent way to calculate the power necessary to pump a well which will give figures uniformly consistent with actual tests, because of the difficulty of determining the effect of varying well conditions. For instance, a large amount of sand in the oil will increase the power necessary to pump it, while on the other hand gas may be present which will help lift the oil. No numerical value can be placed on these conditions, so the motor capacity for this duty is determined largely by comparison with results obtained on other wells. Owing to the fact that the conditions are generally changeable, it is best to have some reserve motor capacity for pumping. The power input will vary from day to day and even from hour to hour, and may increase considerably in a short time when the well is sanding up. Such variations are not so common, however, where the troubles from sand are few.

The following summary of records from over 200 California oil wells pumped on the beam, gives an idea of the motor load for pumping alone:

Depth of wells	900 to 3100 ft., ave. 1430 ft.
Length of stroke	29 to 32 inches.
Strokes per min	20 to 30, average 24.
Diameter of tubing	3 inches.
Power required	1 to 5 h.p., ave. 3.5 to 4 h.p.

Exceptional wells in California have required as high as 16 to 17 h.p. at times. In Louisiana some heavy pumping wells have been encountered, one in the Evangeline field requiring the following:

Depth of pumping	1100 ft.
Length of stroke	30.5 in.
Strokes per min	40
Diameter of tubing	2.5 in.
Power required	9.5 h.p.

Another Louisiana well in the Caddo field gave test results as follows:

Depth of pumping	1000 ft.
Length of stroke	37.5 in.
Strokes per min	38.
Diameter of tubing	3 in.
Power required	17.5 h.p.

Compared with the California wells, these Louisiana wells have a longer stroke, higher speed, larger percentage of water and less gas in the oil, and therefore require more power. The

Caddo well, compared with the one in the Evangeline field, has a little lower speed, but larger tubing and less gas in the oil, and therefore takes more power. The depth of well does not usually appear to be a factor from which any logical conclusions can be drawn.

It is interesting to note that the counterweight which is now quite widely used on the walking-beam to counterbalance the weight of the rods in the well was originally installed to reduce the motor load fluctuation on each stroke, and was found to effect a saving in power as high as 22 per cent in some instances. Its use has since been extended in many cases to engine-driven rigs.

Where changes are frequently taking place in well conditions such as the rate of oil flow, the amount of sand with it, the amount of gas or water in the oil, the viscosity of the fluid or the condition of the pump itself, it is necessary to have a variable speed motor to permit the operator to pump at what he considers is the maximum economical rate, which may be limited by the rate of oil flow or the rapidity with which the rods and plunger will drop in the oil on the down stroke. On the other hand there are many cases where squirrel-cage motors meet all the requirements of pumping.

Pulling the rods and tubing is ordinary hoisting work, carried on at a maximum speed of the band-wheel which may be from 50 per cent to 100 per cent higher than the pumping speed. It demands an intermittent motor output of from 35 to 80 h.p. or even higher under some circumstances. A high torque machine is therefore most suitable. The greatest heating of the motor occurs when handling rods, because of the very frequent reversals which may occur from three to five times a minute for an hour and a half to two hours at a time. Low armature inertia is consequently very desirable. Pulling tubing requires the highest torque and determines the size of motor necessary. The rating usually given the motor for this duty is merely nominal, as the maximum torque obtainable is the determining feature. The maximum load is that encountered when lifting together the rods and pump and the tubing full of oil. In determining the motor capacity it is convenient to use the following formula for the horse power required to lift tubing at a uniform rate of speed:

$$\text{h.p.} = \frac{W \times d \times N}{63{,}000 \times L}$$

in which W = weight lifted in lbs.
d = diameter of bull-wheel shaft in inches.
N = rev. per min. of bull-wheel.
L = number of lines used in the tackle.

The constant 63,000 is based on a mechanical efficiency of the rig of 50 per cent. This is a fair assumption for the majority of cases, as will be seen by reference to Fig. 8, which is an approximate efficiency curve plotted from the results of several tests. In addition to the value obtained from this formula there must remain a sufficient margin in torque for acceleration. This depends largely upon the flywheel effect of the motor armature, as the revolving parts of the rig have relatively small inertia.

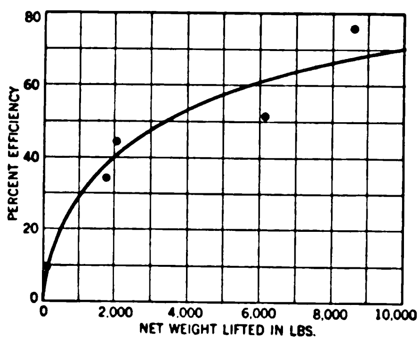


FIG. 8—APPROXIMATE MECHANICAL EFFICIENCY OF STANDARD AMERICAN OIL WELL RIG

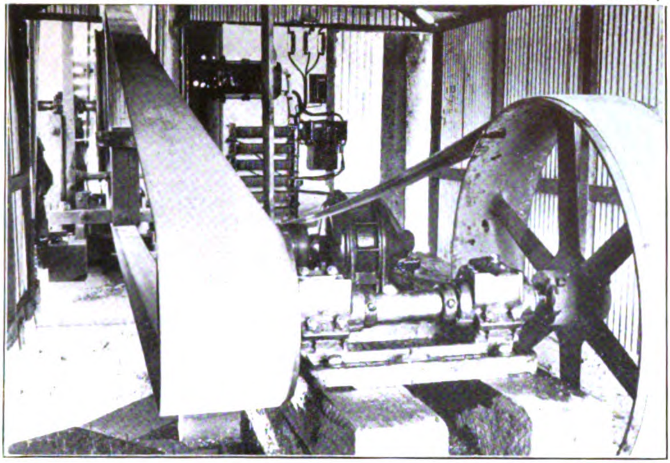
Of the various operations of cleaning a well, swabbing requires the heaviest demand of power. The work consists of lowering a plunger into the well casing and then pulling it out. The plunger has a tight fit in the casing so that the suction thus produced draws the sand out of the perforations at the bottom and thus clears the oil passages. The operation may be performed for several hours at the rate of two to four times per hour, each hoisting trip of the swab requiring several minutes. Peak inputs to the motor from 40 to nearly 70 kw. have been recorded in this work.

The total monthly power consumption for all the work of pumping, pulling and cleaning a well will vary from approximately 1350 to 6000 kw-hr. but the average is about 2100 kw- hr.

The necessity of employing a single motor for all of the work of pumping, pulling and cleaning is due chiefly to two reasons; first, the impracticability of using a portable hoisting equipment for wells that may have to be pulled every few days, particularly where the country is rough; second, the desire of a great majority of operators to have a machine which will take the place of the steam engine with little or no change in the method of operation.

The most successful and most widely used induction motors for this duty are of two types, the 'Y-delta' and the two-speed. Except in special instances both are of the slip-ring type, the former being designed for changing the normal capacity by a change in stator connections made by a suitable switch, this not, however, affecting the speed; the latter has a pole-changing switch mounted on the frame by means of which both the speed and capacity are changed. Both machines require a controller and secondary resistance for speed variation, which with the two-speed motor are effective on either the high or the low speed connection, as a six-phase rotor winding is used. A synchronous speed of 900 or 1200 rev. per min. is usually selected for either type of motor, and a half-speed connection is used on the two-speed machine. Various ratings are employed, depending upon what the conditions require, among which are 20/7 h.p., 20/10 h.p., 25/8 h.p. and 30/15 h.p. Smaller motors than these generally cannot develop the overload torque occasionally necessary in emergencies on nearly all wells. The low capacity is used for little else but pumping, and the design is therefore made for as high an efficiency as possible on this connection without sacrificing the required torque on the higher rating. The maximum momentary capacity is from 300 per cent to 450 per cent of the high rating, but full-load efficiencies of from 75 per cent to 85 per cent, and power factors nearly as good, are nevertheless obtained at full load on pumping duty.

With the Y-delta motor, a high speed for pulling can be obtained only by changing the pulley or by lagging up the bull-wheel shaft to a large diameter. Few operators care to be bothered with the pulleys, while there are some who will not consider the other method because of the increased strain on parts of the rig. Lagging the bull-wheel shaft furthermore does not speed up the sand-reel, so bailing must be done very slowly. But where the operator will use a lagged shaft and has no sand-reel, the Y-delta motor does very well, except for one point which

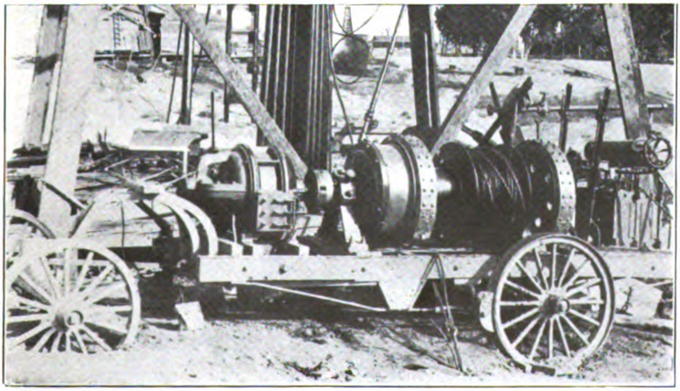


[TAYLOR]

FIG. 11—TYPICAL INSTALLATION OF A TWO-SPEED BELTED MOTOR FOR PUMPING, PULLING AND CLEANING WORK IN THE MIDWAY FIELD IN CALIFORNIA

[TAYLOR]

FIG. 12—BACK-GEARED OIL WELL MOTOR OF THE Y-DELTA TYPE IN THE KERN RIVER OIL FIELD IN CALIFORNIA



[TAYLOR]

FIG. 13—PORTABLE ELECTRIC HOIST USED FOR PULLING AND BAILING OIL WELLS PUMPED BY PUMPING JACKS IN THE KERN RIVER OIL FIELD IN CALIFORNIA

in many cases is important. It is very often the practise to 'shake-up' a well to free the pump valves from sand and thus avoid pulling the rods and tubing. This is accomplished by increasing the speed of the walking-beam for a few minutes, but there is no practical way to do so with this type of motor, as the time required to change pulleys makes this method out of the question. The two-speed slip-ring motor, as may readily be seen, overcomes all these difficulties and has therefore received wide-spread approval by practical oil men. One of these motors is illustrated in Fig. 9.

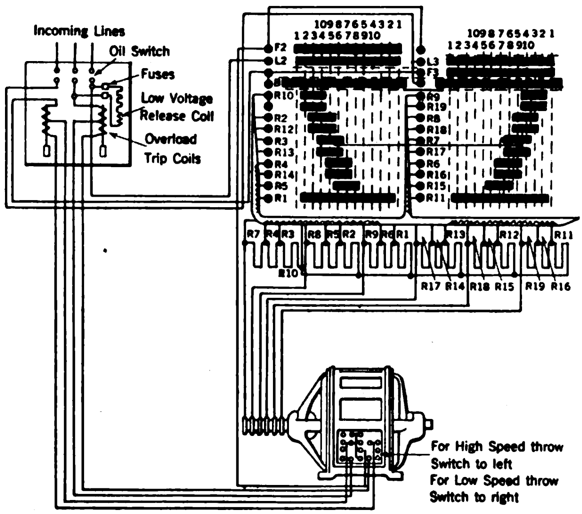


FIG. 10—CONNECTIONS FOR TWO-SPEED MOTOR EQUIPMENT FOR PUMPING, PULLING AND CLEANING DUTY

The connections of the two-speed equipment in Fig. 10 show the method of protecting the double-rated motors by double-wound overload trip coils on the oil switch, which are so interlocked by connections with the switch on the motor that proper protection is automatically obtained. The controller is operated by a rope wheel from the derrick as described for the drilling motor.

While the majority of installations use a belted motor with countershaft, there are many back-geared machines in operation, the two arrangements being shown in Figs. 11 and 12. Oil men display a preference for the former, but most of the gear noise

has been eliminated on the most recent back-geared installations by the use of cloth pinions, and it is anticipated that more of these will be used in the future.

The use of separate motors for pumping and pulling work requires little comment, as it is a simple proposition to select machines with the proper characteristics. The hoist motor must be portable, and either it may be coupled to a hoist mounted on a truck as shown in Fig. 13, or the motor equipment may alone be portable and designed to be belted to the countershaft at each well. Both methods are successfully used. The complete portable hoist is better adapted for wells pumped by pumping-jacks.

Pumping-jacks are operated together from a central point, the reciprocating motion being obtained by eccentrics or cranks which are belt driven. Motors have been applied to a large number, but no features of unusual interest are involved, as the duty is non-reversing and a friction-clutch is frequently used for starting the load. It is an interesting comparison with the individually driven well to note that the power required for jack-rig pumping averages approximately 2.5 h.p. per well and the average consumption is from 30 to 45 kw-hr. per day. The use of jacks has more than cut the power bill in two in some cases, but they are considered advisable only when the well production falls very low, as their use causes a loss of from 15 per cent to 25 per cent in production because of the impossibility of running each well at its most advantageous speed.

Oil well motors have been used in eastern United States fields for the past twelve years, but active interest was not taken in them in California and the middle west until 1910. The conditions encountered in those fields required the development of the equipments described in this paper, which with little or no change can successfully meet any conditions so far encountered in this country. During the first three years over a thousand wells were electrified in California alone. Although very little development work has taken place in the fields during the past two years due to the very low market price of oil, it is estimated that there are between 1500 and 2000 electrically-operated oil wells in the United States at the present time.

No attempt has been made in this paper to give comparative operating costs, as a considerable amount of valuable data on that subject has already been published and is readily available to those interested.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

(Subject to final revision for the Transactions.)

THE EFFECT OF HIGH CONTINUOUS VOLTAGES ON AIR, OIL, AND SOLID INSULATIONS

BY F. W. PEEK, JR.

ABSTRACT OF PAPER

The dielectric strength of air, oil and solid insulations was determined for d-c. voltages up to 150 kv.

The d-c. visual corona voltage is equal to the maximum a-c. corona voltage for wires varying in radius from 0.013 cm. to the largest sizes. The variation of d-c. and a-c. corona voltages with air density is the same over a large range. The laws already given for a-c. voltages apply equally well for d-c. voltages in terms of maximum values.

The spark-over of gaps is the same on alternating current and direct current for equal maximum voltages when the gap is such that spark-over precedes corona. Thus, for the sphere gap the same laws apply for a-c. or d-c. voltages. This is true at various air densities.

When corona precedes spark-over there is generally a difference in a-c. and d-c. spark-over voltages. For a non-symmetrical gap, spark-over at normal air density takes place at the lowest voltage when the electrode surrounded by the denser field is (+). At low air densities spark-over takes place when the electrode surrounded by the denser field is (−).

Insulators spark-over at the lowest voltage when the cap, or electrode surrounded by the denser field, is (+). The (+) spark-over voltage generally corresponds closely to the maximum a-c. spark-over voltage.

The d-c. spark-over voltages in oil generally correspond closely to the maximum a-c. spark-over voltages. In wet oil the d-c. spark-over voltage is lower than the a-c.

The d-c. breakdown voltages of solid insulations, in good condition, are generally higher than the maximum a-c. voltages. This is especially so when the time of application is long and the insulation is thick. The d-c. breakdown voltage on insulations tested apparently increases directly with the thickness, while the a-c. breakdown voltage increases at a lesser rate. Laws are given.

When the insulation is moist, the d-c. and maximum a-c. breakdown voltages are generally approximately the same.

It appears that high voltage direct current would be useful in certain high voltage cable testing, etc.

HIGH CONTINUOUS or "direct-current" voltages were obtained from the 60 cycles alternating by means of a kenotron rectifier in combination with condensers and inductance coils.[1] A sketch of the connections used is given in Fig. 1.

1. These tests were made with kenotrons loaned by Dr. Dushman of the Research Laboratory of the General Electric Company.

Manuscript of this paper was received May 21, 1916.

The condensers are charged up to the maximum of the alternating voltage wave. They remain at this voltage if there is no leakage, and no power is being taken at *A*. If current flows at *A* the condensers become partly discharged between the maximums of two waves and there is a double frequency ripple on top of the " d-c. " voltage across *A*. With a given current taken at *A* the amplitude of this ripple decreases with increasing condenser capacity and increasing inductance. With a given capacity and inductance the ripple decreases with decreasing current at *A*. With a given condenser and inductance the amplitude of the ripple decreases with increasing supply frequency.[2] The variation is less for connection 1*a* than 1*b*. Fig. 2 is an oscillogram of a wave taken with connection as shown in Fig. 1a and 0.05 amperes flowing—60 cycle supply. (This

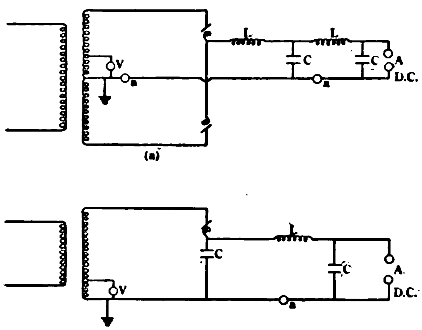


FIG. 1—CONDENSER CAPACITY = 0.064 MICROFARAD

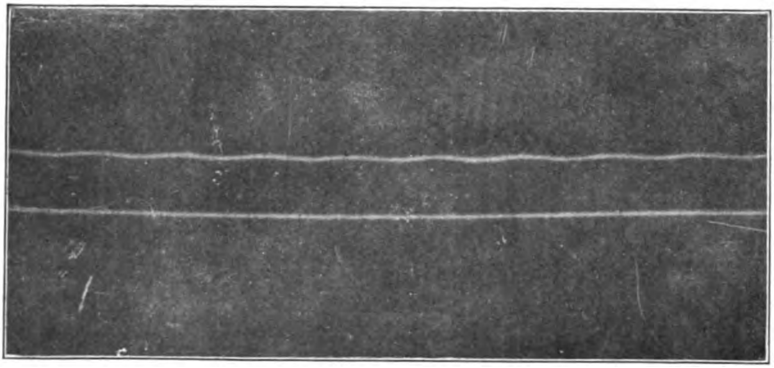
is many times the current flowing in the following tests.) Since in the following tests, the current flowing up to breakdown was practically negligible, there was no appreciable ripple on the voltage wave. Voltage was first measured with a static voltmeter, and by maximum of the wave on the voltmeter coil. When no power was taken the static voltmeter checked with the maximum of the alternating wave, and later, with sphere gap measurements.

AIR

Sphere Gaps. Sphere-gap curves were taken on 6.25- and 12.5-cm. spheres. The continuous, or d-c., voltage required to spark over a given gap was found to be $\sqrt{2}$ times the required

2. See discussion by Dr. Hull, *G. E. Review*, March 1916.

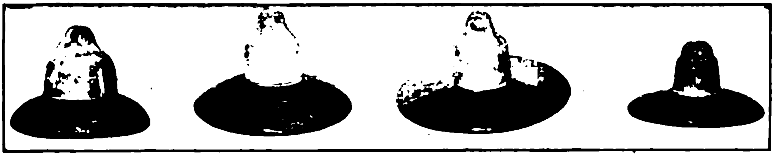
The author wishes to acknowledge indebtedness to Mr. B. L. Stemmons for his skillful assistance in making experiments and calculations.



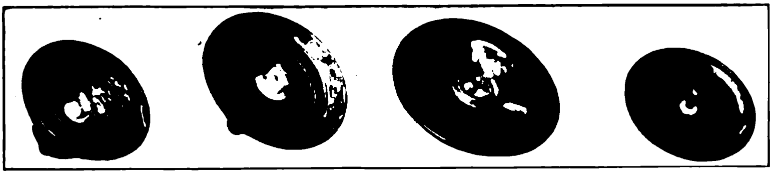
[PEEK]

FIG. 2—WAVE OF RECTIFIED VOLTAGE (25 KV., 0.05 AMPERE, 7-28-15).

Note: There was no appreciable ripple in voltages used in the tests. When the above oscillogram was taken a comparatively large current was allowed to flow in order to exaggerate the ripple.



1 3 4 5



1 3 4 5 [PEEK]

FIG. 9

effective sine wave alternating or a-c. voltage, that is, the d-c. spark-over voltage and the a-c. maximum voltage are equal. See Fig. 3. This is true for various air densities as shown in Fig. 4. The d-c. spark-over voltage curve of a sphere may, therefore, be calculated from the formula already given for a-c. voltages.[3]

$$e = g\,\frac{x}{f}$$

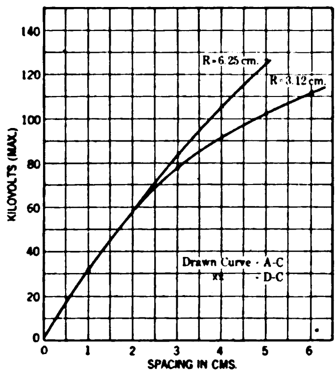


FIG. 3—A-C. AND D-C. SPARK-OVER VOLTAGES FOR SPHERES

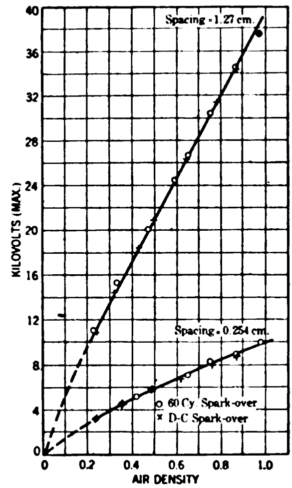


FIG. 4—SPARK-OVER VOLTAGES OF 2.54 CM. SPHERES AT VARIOUS AIR DENSITIES

Where

$$g = 27.2\,\delta\left(1 + \frac{0.54}{\sqrt{\delta\,R}}\right)$$

x = spacing in cm.

$$\delta = \frac{3.92\,b}{273 + t} \qquad b = \text{barometric pressure in cm.} \quad t = \text{temperature, deg. cent.}$$

R = sphere radius in cm.

$$f = \phi\left(\frac{x}{R}\right)$$ (See reference below.)

3. F. W. Peek, Jr., *The Sphere Gap as a Means of Measuring High Voltages.* A. I. E. E. PROC., June 1914.

This voltage may also be found by multiplying voltage value in standard curve by $\sqrt{2}$.

Needle Gaps. The d-c. needle gap spark-over voltage corresponds approximately to the maximum a-c. spark-over voltage

TABLE I.
A-C. AND D-C. SPARK-OVER VOLTAGES OF 2/0 NEEDLES IN AIR.

Spacing, cm.	Kilovolts 60 cycle (max.)	Kilovolts d-c.
5 1	51.0	52.0
7.6	62.5	63.0
10 2	76.5	73 5
12.7	88.3	82.5
15.3	98.3	90.5

over a considerable range. At the higher values the continuous spark-over voltage seems to be less than the maximum alternating. The results are plotted in Fig. 5.

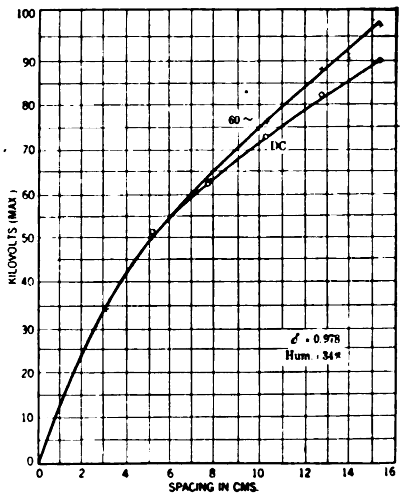


FIG. 5—SPARK-OVER OF 2/0 NEEDLES IN AIR

Corona. Visual corona and spark-over tests were made on concentric cylinders.[4] Typical data are given in Table II,

4. See D-c. Corona Investigations of Watson, *Electrician*, London, 1909-1910, *Journal Inst. of Elec. Eng's*, June 1910. Also, Farwell, A. I. E. E. PROC., November, 1914.

and plotted in Fig. 6. In this test the outer cylinder was 3.81 cm. in radius. The polished inner cylinders or wires and tubes varied from 0.0038 cm. to 1.11 cm. radii.

TABLE II.

D-C. AND A-C. VISUAL CORONA AND SPARK-OVER VOLTAGES

(CONCENTRIC CYLINDERS—NORMAL AIR DENSITY $\delta = 1$)

R radius outer cylinder cm.	r wire radius cm.	R/r	Corona					Spark-Over		
			60 cycle calc. kv. (max)	D-c. + kv.	D-c. − kv.	A-c. $\mathcal{E}_{v\,max}$ kv./cm	D-c. $\mathcal{E}_v$ kv./cm	60 cy. kv. max.	D-c. + kv.	D-c. − kv.
3.81	0.0038	1000.0	4.9	6.4	6.4	186.0	244.0	..	Vibrates before sparkover	
3.81	0.0129	295.0	8.4	8.4	8.3	113.0	113.0	70.0		
3.81	0.0573	66.5	17.2	17.2	17.2	71.5	71.5	40.0	52.8	61.0
3.81	0.130	29.3	25.2	25.2	25.2	56.9	56.9	25.5	48.8	54.5
3.81	0.239	16.0	33.5	33.8	33.8	51.0	51.3	33.9	47.5	52.8
3.81	0.635	6.0	48.9	49.0	49.0	42.9	43.0	48.1	49.5	53.2
3.81	1.110	3.4	54.7	54.8	54.8	40.5	40.6	54.5	54.5	55.5

These data show that the maximum a-c. and the d-c. corona voltages are equal for wires over a large range of sizes. The spark-over voltages are equal when $\frac{R}{r} < \epsilon$ or where cor-

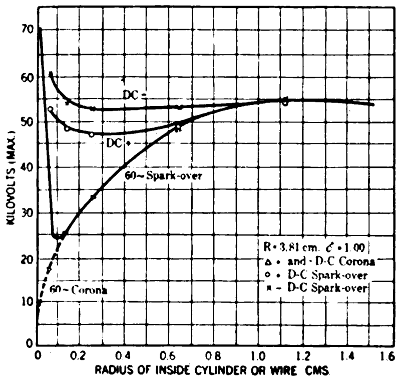


FIG. 6—A-C. AND D-C. CORONA AND SPARK-OVER FOR VARIOUS SIZES OF WIRE (CONCENTRIC CYLINDERS AT NORMAL AIR DENSITY).

ona does not precede spark-over. Where corona precedes spark-over the d-c. voltage is higher than the a-c. The d-c. spark-over voltage is higher when the wire or conductor of the greatest field intensity is (−). This is shown in Fig. 6.

Effect of Air Density on Corona and Spark-over of Wires. The visual corona and spark-over voltages were measured for concentric cylinders at various air densities. An outer cylinder of

TABLE III.
D-C. AND A-C. VISUAL CORONA VOLTAGES
(CONCENTRIC CYLINDERS AT VARIOUS AIR DENSITIES)

R	r	R/r	δ	A-c. calc. 60 cy. kv(max.)	D-c. + kv.	D-c. − kv.	A-c. calc. $\mathcal{E}_v$ kv/cm. (max.)	D-c. $\mathcal{E}_v$ + kv/cm.	D-c. $\mathcal{E}_v$ − kv/cm.
2.90	0.0573	50.5	0.995	15.8	15.8	15.8	....	70.5	....
2.90	0.0573	50.5	0.838	14.2	14.2	14.2	....	63.2	....
2.90	0.0573	50.5	0.770	13.2	13.5	13.2	58.6	60.0	58.6
2.90	0.0573	50.5	0.720	12.6	12.7	12.4	56.0	56.5	55.2
2.90	0.0573	50.5	0.522	10.3	10.3	10.0	45.9	45.9	44.5
2.90	0.0573	50.5	0.363	7.9	8.1	7.8	35.1	36.0	34.7
2.90	0.0573	50.5	0.214	5.7	5.8	5.6	25.3	25.8	24.9

glass coated with the foil was used for these tests. The air was exhausted and the corona and spark-over voltages measured at different air pressures. The apparatus was the same as

TABLE IV.
D-C. AND A-C. VISUAL CORONA VOLTAGES.
(CONCENTRIC CYLINDERS AT VARIOUS AIR DENSITIES.)

R radius outer cylinder cm.	r radius wire cm.	R/r	δ	A-c. calc. 60 cy. kv(max.)	D-c + kv.	D-c. − kv.	A-c. calc. $\mathcal{E}_v$ (max.)	D-c. $\mathcal{E}_v$ + kv/cm.	D-c. $\mathcal{E}_v$ − kv/cm.
2.90	0.239	12.1	1.00	30.0	30.0	30.0	50.5	50.5	50.5
2.90	0.239	12.1	0.915	28.0	27.8	27.8	47.0	46.8	46.8
2.90	0.239	12.1	0.857	26.3	..	26.2	44.2	....	44.0
2.90	0.239	12.1	0.824	25.7	25.5	..	43.3	42.9	..
2.90	0.239	12.1	0.797	25.1	..	25.1	42.2	....	42.2
2.90	0.239	12.1	0.720	23.1	23.1	..	38.8	38.8	....
2.90	0.239	12.1	0.680	22.1	..	22.1	37.1	37.1	....
2.90	0.239	12.1	0.550	19.1	19.2	19.3	32.1	32.2	32.4
2.90	0.239	12.1	0.435	15.7	15.7	16.0	26.4	26.4	26.9
2.90	0.239	12.1	0.357	13.5	13.5	..	22.7	22.7	....
2.90	0.239	12.1	0.260	10.7	10.9	11.6	18.0	18.4	19.5
2.90	0.239	12.1	0.082	4.8	4.4	4.6	8.07	7.4	7.75

that used in a-c. tests and already described[5]. The results are given in Tables III, IV and V, and plotted in Figs. 7 and 8.

The data in Tables III and IV show that the maximum a-c.

5. F. W. Peek, Jr., *Law of Corona*, A. I. E. E. TRANS., 1912, 1913.

and the d-c. visual corona voltages correspond down to $\delta = 0.3$. The difference is not great even at $\delta = 0.08$. The difference at the lower values of δ may be due to the difficulty in determining the exact starting point in these cases.

TABLE V.
D-C. AND A.C. SPARK-OVER VOLTAGES.
(Concentric Cylinders at Various Air Densities.)

R radius outer cylinder cm.	r radius wire cm.	R/r	δ	60 cy. kv. max.	D-c. + kv.	D-c. − kv.
2.90	0.239	12.1	0.075	4.2	4.8	4.6
2.90	0.239	12.1	0.250	10.6	11.1	10.8
2.90	0.239	12.1	0.354	12.5	14.2	14.4
2.90	0.239	12.1	0.477	16.8	17.2	18.3
2.90	0.239	12.1	0.660	21.6	22.0	23.5
2.90	0.239	12.1	0.760	24.2	24.5	26.3
2.90	0.239	12.1	0.890	27 2	27.2	30.0
2.90	0 239	12.1	1.000	30.1	30.5	3.7

See corona data on this cylinder—Table IV.

Spark-over data are given in Table V for a 0.239-cm. wire. At the higher values of δ the positive spark-over voltage is lower than the negative and closely follows the maximum a-c. The positive seems to be slightly higher than the negative for very low values of δ.

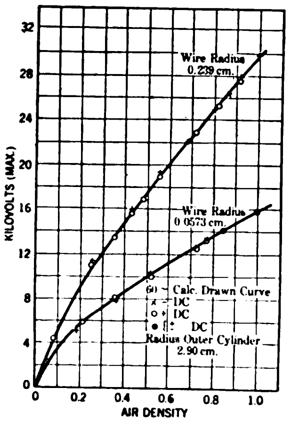


Fig. 7—Variation of A-C. and D-C. Visual Corona Voltages with Air Density

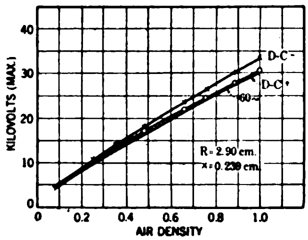


Fig. 8—D-C. Spark-over of Concentric Cylinders at Various Air Densities

These tests show that the formula already given for a-c. corona may also be used for d-c. corona over a wide range of wire diameter, air density, etc.[6] The d-c. corona voltage is equal to the maximum a-c. corona voltage.

6. F. W. Peek, Jr., *Law of Corona and Dielectric Strength of Air.* A. I. E. E. Trans., 1911, 1912.

The d-c. visual corona voltage in kilovolts is

$$e_v = g_v r \log_e \frac{R}{r} \quad \text{wire in a cylinder}$$

$$e_v = 2 g_v r \log_e \frac{R}{r} \quad \text{parallel wires}$$

Where

$$g_v = g_0 \, \delta \left(1 + \frac{0.3}{\sqrt{\delta \, r}}\right) \text{ kv. per cm.}$$

where $g_0 = 31$ (concentric cylinders)

$g_0 = 30$ (parallel wires)

$$\delta = \frac{3.92 \, b}{273 + t} \qquad \begin{aligned} b &= \text{barometric pressure cm.} \\ t &= \text{degrees centigrade.} \end{aligned}$$

Surface Spark-over of Insulators. Spark-over tests were made on several standard insulators shown in Fig. 9. The results are plotted in Table VI. The spark-over voltage is highest when the cap or electrode around which the field intensity is highest is (–). This checks with the impulse tests.[7] When the cap is (+) the d-c. spark-over voltage generally very nearly coincides with the maximum a-c. spark-over.

TABLE VI.
SURFACE SPARK-OVER OF SUSPENSION INSULATORS.

Insulator number	60 cycle kv. (max.)	D-c. kv.	
		cap +	cap –
1	116.0	117.5	127.5
2	99.0	99.0	106.0
3	126.0	132.0	139.0
4	111.5	128.0	135.0
5	119.0	128.0	135.0

OIL

The "corona" and spark-over characteristics of oil are very similar to those of air. Practically the same laws are followed

7. F. W. Peek, Jr., *The Effect of Transient Voltages on Dielectrics.* A. I. E. E. PROC., August, 1915.

for a-c. voltages in both oil and air.[8] This apparently also holds for d-c.

Needle gap spark-over voltages for oil are given in Table VII

TABLE VII.

D-C. AND A.C SPARK-OVER TESTS ON 2/0 NEEDLES IN NO. 8 TRANSIL OIL AT 25 DEG. CENT.

Needle gap cm.	60 cycle kv. (max.)	D-c. kv. (max.)
0.317	21.2	21.7
0.635	34.7	33.5
1.27	50.5	50.2
1.91	65.0	66.0
2.54	86.5	82.5

and plotted in Fig. 10. The d-c. voltages correspond to the a-c. maximum.

The effect of moisture on the strength of oil for a-c. and d-c voltages is given in Table VIII and Fig. 11.

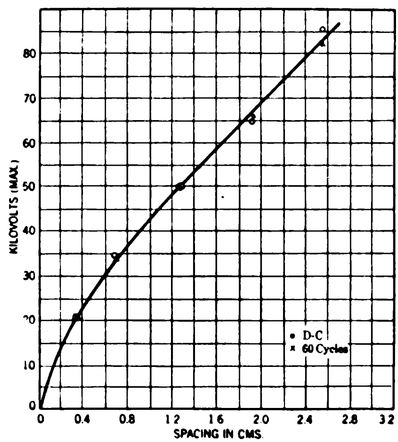


FIG. 10—A-C. AND D-C. SPARK-OVER VOLTAGES OF 2/0 NEEDLES IN NO. 8 TRANSIL OIL AT 25 DEG. CENT.

When the oil is wet the d-c. breakdown voltage is lower than the a-c. breakdown voltage. This is probably due to lining up of water particles under direct current.

8. F. W. Peek, Jr., *Law of Corona and Spark-over in Oil.* *G. E. Review*, August, 1915, also *Dielectric Phenomena in High Voltage Engineering.* Chap. IV.

Solid Insulations

In air and in oil there is no appreciable loss until local breakdown occurs in the form of corona or brushes. In solid insulations loss starts as soon as voltage is applied and generally in-

TABLE VIII.
EFFECT OF MOISTURE ON THE DISRUPTION OF NO. 8 TRANSIL OIL AT 25 DEG. CENT.
(Between 1.27 cm. Diameter Disks at 0.5-cm. Spacing)

Parts water added in 10,000	60 cycle kv. (max.)	D-c. kv.
0	62.3	61.5
0.5	33.5	34.7
1.0	33.4	34.3
2.0	31.7	30.2
5.0	27.3	24.7
10.0	25.4	23.0

creases as the square of the voltage. The heating which results increases the loss and weakens the insulation. Practically all solid insulations absorb moisture. The interstices in the non-homogeneous structure become filled with moisture and gases.

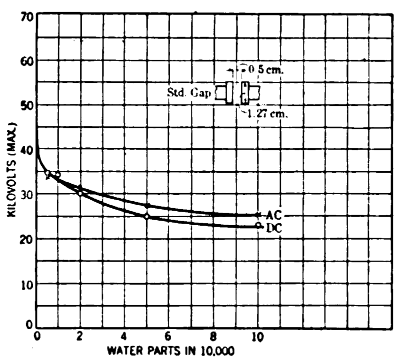


Fig. 11—Effect of Moisture on Disruptive Strength of No. 8 Transil Oil At 25 Deg. Cent.

This makes, in effect, not only a complicated arrangement of resistances, but also of resistances and capacities in series throughout the material. Where the conducting paths extend through from terminal to terminal, either alternating or direct current can flow. But where the conducting paths extend partly through

the structure they are, in effect, resistances in series with capacities; only alternating current can flow through these paths. The effective resistances as measured by alternating current and by direct current are quite different except in those solid insulations in which the " conducting " paths are arranged from terminal to terminal. The voltage distribution, heating, etc., will generally not be the same for a-c. and d.c. voltages. In the homogeneous materials, air and oil, d-c. breakdown voltages correspond to the maximum 60 cycle a-c. breakdown voltages. In most solid insulations relatively higher d-c. values should be

TABLE IX.

VARIATION OF 60 CYCLE PUNCTURE VOLTAGE WITH TIME OF APPLICATION ON VARNISHED CAMBRIC.

TESTS BETWEEN 2.5-in. PLATES, 1¼-IN. RADIUS EDGE, IN NO. 6 TRANSIL OIL.

Temperature deg. cent.	Sheets in.	Thickness mm.	kv. (max.)	Time sec.
25	1	0.30	24.8	2.3
		(12 mils)	21.3	12.0
			19.5	17.3
			17.7	41.5
			15.9	198.0
			14.2	900.0
100	1	0.30	14.5	2.0
			13.2	7.0
			12.6	11.0
			12.0	25.0
			10.8	620.0
			9.9	1400.0
25	2	0.60	29.8	213.0
			26.7	700.0
			25.6	1418.0
25	3	0.90	53.0	8.0
			45.2	51.5
			42.5	80.0
			41.7	138.0
			38.9	370.0
			37.1	905.0
25	4	1.20	69.3	4.0
			65.0	13.0
			64.3	15.0
			55.8	39.0
			53.0	80.0
			50.8	155.0
			47.3	580.0

expected, especially in insulations where the a-c. and d-c. "resistances" are decidedly different.

Varnished Cambric. Because of the effects of heating due to losses, voltage-time curves are necessary in order to compare the strengths of solid insulations. A-c. and d-c. voltage-time curves

TABLE X.
VARIATION OF D-C. PUNCTURE VOLTAGE WITH TIME OF APPLICATION ON VARNISHED CAMBRIC.
TESTS BETWEEN 2.5-IN PLATES, 1¼-IN. RADIUS EDGE, IN NO. 6 TRANSIL OIL.

Temperature deg. cent.	Sheet in.	Thickness mm.	kv. (max.)	Time sec.
25	1	0.30	28.8	8.3
			27.2	20.0
			25.5	54.0
			23.8	94.0
			22.1	363.0
			20.4	668.0
			18.8	5400.0
100	1	0.30	21.0	1.5
			20.3	2.0
			19.6	38.0
			18.6	72.0
			17.0	600.0
			15.9	470.0
			15.2	1920.0
25	2	0.60	52.5	26.0
			50.0	50.0
			47.0	230.0
25	3	0.90	80.3	68.0
			77.5	130.0
			77.2	350.0
			75.5	1400.0
25	4	1.20	127.2	7.0
			120.0	16.0
			115.2	45.0
			110.0	100.0
			107.5	185.0
			105.0	330.0
			104.6	730.0

were taken on varnished cambric. The insulation under test was placed in transil oil between 5-cm. diameter brass plates with rounded edges. A given voltage was applied and time noted until breakdown occurred. The break-down voltages for various thicknesses of varnished cambric in the approximately

uniform field between parallel plates is given in Tables IX and X and plotted in Figs. 12 and 13.

Fig. 12 shows that the d-c. puncture voltage for a given thickness of cambric and for a given time of application is higher than the maximum a-c. puncture voltage. Fig. 13 shows that both the a-c. and d-c. puncture voltages decrease with increasing temperature. (The temperature referred to is that of the oil bath in which the insulation is immersed.)

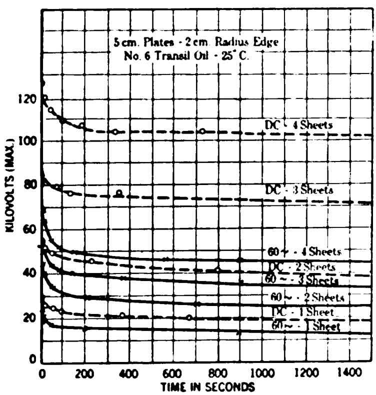


FIG. 12—VARIATION OF D-C. AND A.C. PUNCTURE VOLTAGES WITH TIME OF APPLICATION—VARNISHED CAMBRIC

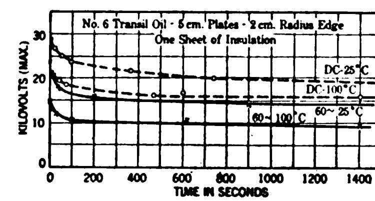


FIG. 13—EFFECT OF TEMPERATURE ON THE A-C. AND D-C. DISRUPTIVE STRENGTH OF VARNISHED CAMBRIC

The curves between puncture voltage and time are closely approximated by the equation[9]

$$e = e_0 \left(1 + \frac{a}{\sqrt[4]{T}}\right) \text{ kilovolts}$$

or the unit strength by

$$g = g_0 \left(1 + \frac{a}{\sqrt[4]{T}}\right) \text{ kv. per mm.}$$

Where

e = puncture voltage in time T, kilovolts (max.)
T = time in seconds.
e_0 = puncture voltage for $T = \infty$, kv. (max.)
g = breakdown gradient in time T, kv. per mm.
g_0 = breakdown gradient in $T = \infty$, kv. per mm.
a = depends upon the kind and thickness of the insulation and frequency.

9. F. W. Peek, Jr., *Electrical Characteristics of Solid Insulation, G. E. Review*, November, 1915. Also Dielectric Phenomena in High Voltage Engineering. Chap. VII.

This equation seems to hold well for a range of time between $T = 1$ and $T = \infty$. The breakdown voltage is plotted with $\frac{1}{\sqrt[4]{T}}$ in Fig. 14. The result is a straight line from which the above relation is obtained.

In Fig. 15 the a-c. and d-c. breakdown voltages of varnished

TABLE XI.

A-C. AND D-C. PUNCTURE VOLTAGES OF VARNISHED CAMBRIC FOR VARIOUS THICKNESSES AND TIME OF APPLICATION

Time of application, seconds		∞	100	50	10	2
Sheets	Thickness mm.	Kilovolts to puncture (max.)				
1	0.30 a-c.	11.0	16.5	17.5	20.5	25.5
	0.30 d-c.	18.0	23.5	24.5	27.5	32.5
2	0.60 a-c.	20.0	31.0	33.0	39.0	47.0
	0.60 d-c.	43.0	49.5	51.0	55.5	62.5
3	0.90 a-c.	30.0	42.0	45.0	52.0	62.0
	0.90 d-c.	70.0	79.0	81.0	86.0	95.0
4	1.20 a-c.	37.0	52.0	55.0	64.0	78.0
	1.20 d-c.	96.0	111.0	114.0	123.0	137.0
		Gradient kv. per mm. (max.)				
1	0.30 a-c.	36.6	55.0	58.5	68.5	85.0
	0.30 d-c.	60.0	75.0	82.0	92.0	108.0
2	0.60 a-c.	33.3	51.5	55.0	65.0	78.0
	0.60 d-c.	72.0	82.0	85.0	92.0	104.0
3	0.90 a-c.	33.3	46.5	50.0	57.9	69.0
	0.90 d-c.	77.5	87.5	90.0	95.5	105.0
4	1.20 a-c.	30.9	43.3	45.8	53.2	65.0
	1.20 d.c.	80.0	92.5	95.0	102.0	106.0

cambric for the time, $T = \infty$, are plotted with thickness. As $T = \infty$, this is the highest voltage that the insulation will withstand indefinitely without puncture. For this material, at thicknesses from 0.3 mm. to 1.2 mm., the puncture voltage increases directly with the thickness, that is, the d-c. unit breakdown strength or gradient is constant. The unit strength of

solid insulations under a-c. voltages decreases with increasing thickness. For a-c. voltages[10]

$$g = g_0 \left(1 + \frac{a}{\sqrt{t}}\right)$$

or

$$e = g_0\, t \left(1 + \frac{a}{\sqrt{t}}\right)$$

For d-c. voltages apparently

$$g = g_0$$

$$e = g_0 t$$

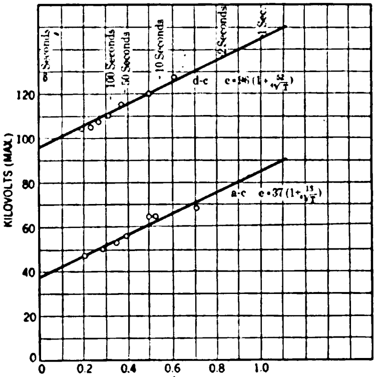


FIG. 14—VARIATION OF A-C. AND D-C. PUNCTURE VOLTAGES WITH TIME

4 sheets (1.20 mm.) Varnished cambric voltage plotted with $1/\sqrt[4]{T}$.

where

e = breakdown voltages of thickness t.
t = thickness in mm.
g = unit strength for thickness t, in kv. per mm.
g_0 = constant
a = depends upon the kind of insulation, time and frequency.

The curves in Fig. 16 correspond to those in Fig. 15 for T = 2 seconds.

It can be seen from the above relations that the ratio between the d-c. and a-c. puncture voltages for solid insulations cannot

10. F. W. Peck, Jr., *Electrical Characteristics of Solid Insulation*, *G. E. Review*, November 1915. Also Dielectric Phenomena in High Voltage Engineering.

be constant but must increase with increasing thickness of insulation, especially where the time of application is long. This is shown graphically in the ratio curves in Figs. 15 and 16. Thus, in Fig. 16, where the time is two seconds, or relatively short, the d-c. puncture voltage very nearly corresponds to the a-c. maximum puncture voltage where the thickness is not great. In Fig. 15, where the time is a maximum, the d-c. puncture voltage is 2.5 times the a-c. maximum puncture voltage or 3.5 times the a-c. effective voltage for a thickness of 1.2 mm.

Some of the d-c. puncture values (Tables X and XI) for single sheets of cambric apparently have a lower unit strength than a

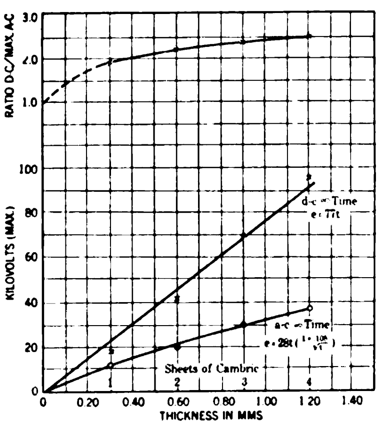


Fig. 15—Variation of A-C. and D-C. Breakdown Voltage with Constant Time

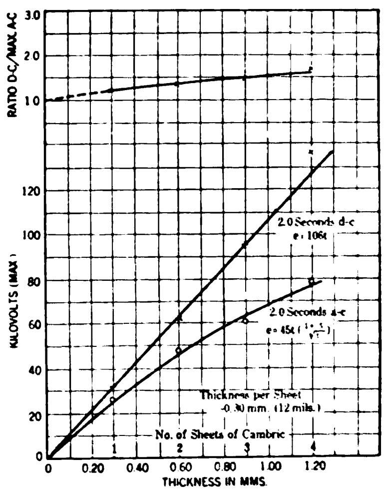


Fig. 16—Variation of A-C. and D-C. Breakdown Voltage with Constant Time

greater number of sheets. This is undoubtedly due to a greater probability of weak spots on a single sheet. Results of the same consistency cannot be expected or obtained on solid insulations as on gaseous and liquid insulations.

The thickness range of the insulation in the above tests was not great; it was limited by the available voltage (150 kv. direct current). It is *possible* that the d-c. unit strength will not remain approximately constant over a wide range.

Wet Insulations. Some 2.4-mm. (3/32-in.) treated pressboard was soaked in water and then partly dried out. A-c. and d-c. tests were made on this poor insulation. The results are given in Table XII.

5 kv. was thrown on the insulation, after the first minute the voltage was increased to 7.5, then to 10, etc., until breakdown occurred. If breakdown occurred before the end of the minute the time was recorded in seconds. For example, in the first a-c. test, insulation No. 6 withstood 60 seconds at 5.0 kv., 60 seconds at 7.5 kv. and 5 seconds at 10 kv. when breakdown occurred. It will be noted that the d-c. and a-c. maximum breakdown voltage average about the same in this insulation which

TABLE XII.

D-C. TESTS ON WET INSULATIONS

0.24-CM (3/32-in.) VACUUM TREATED PRESSBOARD.

(Soaked in water and partly dried.)

Ins. test no.	Megohms res.		Kilovolts max.) 5.0	7.5	10.0	12.5	15.0	17.5	20.0	225
	TIME (Figures show time in seconds at various voltages.)									
6	(120)	a-c.	60	60	5					
			60	60	50					
		d-c.	60	60	12					
			60	60	20					
	(300 - 1500)	a-c.	60	60	60	60	2			
			60	60	60	17				
		d-c.	60	60	40					
			60	60	38					
4	(1000 − α)	a-c.	60	60	50					
			60	60	50					
		d-c.	60	60	60	60	17			
			60	60	30					
5	(2000 +)	a-c.	60	60	60	60	60	60	60	10
			60	60	60	60	60	60	30	
		d-c.	60	60	60	60	60	0		
			60	60	60	60	0			

was conducting from terminal to terminal. In some of the tests, in fact, breakdown takes place at a lower voltage on direct current than alternating current. This is, perhaps, due to a better lining up of moisture by direct current. Some of this insulation, dry and in perfectly good condition, was then tested in the same way. Starting at 5 kv. the voltage was increased every 60 seconds in 2.5-kv. steps until breakdown occurred; breakdown resulted on alternating-current when 70 kv (max.) was reached; on direct-current when 130 kv. was reached.

Similar tests were made on sections of paper-insulated cables that had absorbed varying amounts of moisture. In those sections in the worst condition as indicated by low puncture voltages, the d-c. and a-c. maximum puncture voltages averaged about the same. In the sections in the best condition the d-c. puncture voltage was somewhat higher than the maximum a-c. voltage.

There is considerable difficulty in practise in making a-c. voltage tests on long lengths of cables, due to the size of the apparatus, which is necessarily large on account of charging current. The necessary kilovolt-amperes often amount to several hundred. The wave shape is often distorted by the leading current, the apparatus is difficult to move about etc. D-c. tests would eliminate these difficulties, as very small apparatus would be required, providing such tests would detect faulty sections, etc. It cannot be said that a given d-c. voltage is equivalent to a given a-c. voltage. The above tests indicate, however, that faulty sections of cable could be as equally well located by d-c. tests as by a-c. tests. In cases of cracks, etc. the air- or compound-filled space would be broken down at the same maximum voltage on direct current or alternating current. In case of a fault due to moisture the breakdown would apparently take place at about the some voltage alternating current or direct current. In the case of a cable in good condition there would be much less likelihood of injury by direct current than by alternating current of the same maximum voltage. A d-c. voltage equal to the maximum of the a-c. test voltage would, therefore, seem suitable for such tests.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

THE CORONA VOLTMETER

BY J. B. WHITEHEAD AND M. W. PULLEN

ABSTRACT OF PAPER

An instrument is described in which the first appearance of corona is used as a measure of the applied voltage.

Three methods for detecting the first appearance of corona have been developed, in addition to the method of visual observation. These methods involve the use of the electroscope, the galvanometer, and the telephone respectively.

For a given wire, in fixed relation to the opposite side of the circuit, corona-forming voltage depends on the density of the air, that is, on the pressure and temperature. The corona voltmeter consists of a grounded metal cylinder, with a central conductor on which corona is formed. Both cylinder and conductor are enclosed in a larger, air-tight cylinder, in which the pressure can be varied by a hand pump. This variation in pressure provides the means by which a wide range of voltage reading is possible. The calibration of the instrument is absolute, that is, can be calculated, or may be obtained by comparison with existing standards.

The voltmeter is set for a given voltage by adjusting the pressure to a value calculated from the dimensions of the instrument and taken from a calibration table or curve. When the ascending voltage reaches the value for which the voltmeter is set, corona begins, and this is sharply indicated by any one of the three methods mentioned. To measure an unknown voltage, the pressure is gradually lowered from some higher value and is read at the instant corona appears. A table of calculated values, or a calibration curve then gives the unknown voltage.

Tests showing the constancy and permanence of the instrument are described.

INTRODUCTION

DURING a number of years' intermittent experiment on the phenomena attending the electric break-down of air, one of the most striking observations has been the extreme sharpness, in an ascending range of voltage values, with which this break-down occurs in the form of corona on clean round wires. Under suitable conditions of observation, critical voltage readings repeat themselves to an accuracy equal to that within which the usual direct reading instrument can be read, *i.e.*, of the order of one-tenth of one per cent. This fact has led one of the authors in his papers[1] describing the experiments, to point

1. For references see bibliography at end of paper.

Manuscript of this paper was received April 13, 1916.

several times to its value as a method for measuring high voltage. It has been shown beyond question that the appearance of corona depends on the maximum value of the alternating current wave.

That the visual appearance of corona might be used as a means of measurement of the maximum value of the voltage wave was apparently first suggested by H. J. Ryan[2] in his notable paper of 1904. His suggestion, however, does not seem to have extended beyond the visual observation of the light given out by corona, which naturally is only visible in darkness. Reliance on visual observation therefore, practically precludes the use of the method except perhaps for laboratory purposes. This and the fact that the correction factors for variations of temperature and pressure have only recently been definitely fixed[3], probably explains the absence of attempt, up to this time, to make use of the appearance of corona as a measure of voltage.

The fact that air in the neighborhood of the corona is ionized, that is, possesses high electric conductivity, has been extensively utilized by one of the authors[1] as a means of detecting the presence of corona. A charged electroscope in a suitable location near a high-voltage conductor discharges with marked suddenness on the appearance of corona. The electroscope, then, may be used as a detecting instrument free from the limitations of visual observation of the light of the corona. Other means of detection have also been developed and will be described in this paper. With a suitable detecting instrument therefore the corona becomes far more accessible as a high-voltage indicator.

Little need be said as to the importance of a convenient and reliable method for measuring the maximum value of high alternating voltage. The question is answered by the fact that the electric strength of all insulating material is dependent on the maximum value of applied voltage. The needle gap as a means of measurement may also be passed with only brief comment. Although long the standard of the Institute, its unreliability is now universally recognized. It may be stated, however, that under properly chosen conditions and with points having angles greater than 20 degrees, quite uniform results may be obtained. The thorough investigation of the needle gap by Weicker[4] has shown its limited value and many weaknesses.

The sphere gap has been strongly advocated as an instrument free from many of the objections to the needle gap. The authors

of this paper cannot claim familiarity with this instrument, and therefore, hesitate to call attention to its apparent limitations. It is fair, however, to point out that the results of different observers using the sphere gap are not in agreement, that the results of a single observer frequently differ by several per cent, and that as shown by Peek[5], the calibration curve is widely different for the cases of both terminals insulated, and one terminal grounded. Its accuracy therefore is very sensitive to the proximity or presence of other objects in the neighborhood, due to their influence on the electrostatic field. Attempts have also been made to derive mathematical expressions from which it should be possible to calculate the spark-over voltage of any given sphere gap. However, the results of Russell[6] in this direction have been attacked by de Kowalski and Rappel[7], and the subsequent discussion indicates that there is considerable doubt whether it is possible to calculate accurately the electric intensity within the sphere gap. Therefore notwithstanding the adoption by the Institute of the sphere gap as a standard, no apology is necessary in describing an instrument which seems to be free from some of its imperfections.

Recent papers before the Institute by Chubb[8] and by Sharp and Doyle[9] have described crest voltmeters utilizing the rectifying properties of hot cathode tubes. The arrangement proposed by Sharp and Doyle is especially simple and promising. Both types should prove valuable for low-voltage readings although the use of a vacuum tube is an undesirable feature for general utility. On high voltage, series condensers or resistance are apparently necessary, and therefore introduce well-known uncertainties.

Principle of the Corona Voltmeter

The corona as a means of measurement possesses the great advantage that it obeys a definite law upon which close agreement now obtains among many observers. If it is possible to foretell with a good degree of precision the value of voltage at which corona will begin on a clean round conductor an absolute calibration is therefore also possible. This paper describes an instrument in which the first appearance of corona may be accurately and conveniently detected, and which may be set readily and without trouble for any voltage within a considerable range.

From the nature of the corona it will be evident that an in-

strument using it as an indicator of voltage can make no pretense to a direct-reading scale. No more can the needle gap or the sphere gap. The corona voltmeter as now described, however, possesses, among other advantages, two important features, which in the absence of a direct-reading scale, are very good substitutes. (1) Convenience of observation. (2) A wide range of voltage without manipulation or adjustment of the instrument.

Methods of Observation

The appearance of corona obeys a rigid law only when the wire or rod on which it appears is accurately placed on the axis of a hollow cylinder forming the opposite side of the circuit. This arrangement has therefore been chosen for the voltmeter. In the present form the outer cylinder is grounded, thus presenting the advantage of screening the wire from outside influence and permitting close approach to it without danger.

Three methods of observing the beginning of corona, not including visual observation, have been developed; the electroscope, the galvanometer, and the telephone.

The Electroscope. The electroscope is the most sensitive instrument for detecting the state of ionization or conductivity in a gas. Since the corona is attended by copious ionization the use of the electroscope for detecting corona involves only the question whether the electroscope can be brought into suitable proximity of the corona without disturbing the electric field upon which the formation of the corona depends.

If the outer grounded cylinder surrounding the rod or wire on which the corona is formed is perforated with a few small holes, and an insulated electrode connected to a charged electroscope is brought up close to these holes on the outside, the first appearance of corona causes an immediate discharge of the electroscope. The close coincidence between the appearance of corona and the electroscope leak or discharge was described in the first paper of one of the authors, on the "Electric Strength of Air."[1] So copious is the ionization with the very first appearance of the visual corona that it is not necessary to use a particularly sensitive electroscope. A roughly constructed instrument using a large strip of aluminum foil instead of gold leaf has been used with good advantage.

In order to meet the possible requirement of moving from place to place, a portable electroscope has been developed. This

instrument has only one leaf which, in its zero or discharged position, rests against a rigid member. Means are provided whereby in this position the leaf is pressed throughout its entire length against the rigid member by a flap made of the paper which separates the successive layers of gold leaf in the books in which the leaf is usually furnished. This flap is readily adjustable from outside the instrument, which can thus be handled without danger to the gold leaf. The instrument is also furnished with means for adjusting the sensibility. Since the strip of gold leaf swings through a circular arc it may be calibrated, although this is not necessary for the purpose of indicating the first appearance of corona. Direct visual observation of the discharge of the electroscope is possible but is not as accurate as when it is viewed through a telescope.

The electroscope may be charged from a 120 volt, direct-current circuit, either directly or by a parallel-series connection of small condensers.

The Galvanometer. If the outer grounded cylinder be drilled with small holes fairly close together over its entire surface, and if the electrode formerly used for the electroscope be extended in area so as to form an outer cylinder surrounding that forming one side of the high voltage circuit, a very greatly increased volume of ionized gas may be utilized. If this outer cylinder or electrode is brought close to the grounded cylinder and is connected to ground through a galvanometer and source of continuous potential, the galvanometer should deflect when the gas between the two cylinders is ionized. The outer or electrode cylinder must of course, be carefully insulated.

The object of this arrangement is to detect the presence of corona with a less sensitive instrument than the electroscope. The results as described below indicate that under proper conditions this arrangement serves admirably for its purpose. In the larger of the two voltmeters to be described, a portable needle galvanometer with a direct reading scale and sensitivity of 10^{-5} amperes may be used. For the smaller voltmeter a more sensitive galvanometer is necessary. Up to this time a reflecting galvanometer with telescope has been used, of sensitivity in the neighborhood of 10^{-7} amperes. The magnitude of its deflections indicates that the more sensitive forms of needle galvanometer may, if necessary, be used with this instrument also. For portable purposes, the needle galvanometer is obviously the more desirable.

A continuous voltage is necessary in the use of the galvanometer. The 240-volt, three-wire circuit has been used in the experiments, provision being made for 120 volts positive or negative on the galvanometer and electrode. The arrangement is markedly more sensitive for negative than it is for positive electrode, owing to the differences in the properties of negative and positive ions and consequently the resulting values of the ionization currents.

The Telephone. The corona emits a sound which is gathered and intensified if the region surrounding the corona forming wire is enclosed. Earlier experiments showed that if the perforated grounded cylinder or corona tube has its ends capped and is enclosed in an outer jacket of any kind provided with a single hole to which the ear may be placed, the first appearance of corona is attended by sound of considerable volume. If a cone, connected by tubes to ear pieces is added, the sound is further intensified, and in fact, becomes quite loud.

As described below, the corona voltmeter in its present form involves a variation of the gas pressure in the corona tube. This of course, will prevent a direct listening to the sound. In order therefore, to take advantage of the sound, a telephone transmitter has been inserted into a side tube and connected with twin receivers in the usual head-piece form, on the outside. Obviously gas pressure has no influence on the proper operation of the telephone transmitter. This arrangement has been found to work admirably, and indeed, has been found quite as reliable as either of the foregoing methods for indicating the initial presence of the corona.

Visual Observation. Any of the foregoing methods may be checked in a darkened space by visual observation. In the present work the two forms of instrument have been provided with plate glass disks at their ends, permitting detection of the first appearance of visual corona. As numerous tests have shown that the indications of all three of the foregoing methods are simultaneous with the appearance of corona, the use of the visual method has been limited to the purposes of inspection and checking.

Range of Observation

At atmospheric pressure and temperature, a given diameter of wire or rod, placed in a given outer tube, will form corona at one and only one definite value of voltage. Hence to obtain any range in an instrument using corona under atmos-

pheric conditions would require a change in the diameter of the outer cylinder or of the inner conductor, or in the use of a wire or rod of varying diameter. A change from one conductor to another is not impossible but is manifestly troublesome and objectionable, save perhaps, under laboratory conditions. The use of a conductor of varying diameter is not feasible on account of the small temperature variations due to the presence of corona and on account of the necessity of visual observation.

Corona-forming voltage depends on the pressure and temperature of the air. The values of the voltage at which corona forms on a given wire under any conditions of temperature and pressure are now well-known. The density of the gas is the determining factor and variations of density cause quite wide differences in the value of the corona forming voltage.

A prominent feature of the corona voltmeter as here described is that the pressure in the corona tube is controlled and varied and constitutes the means whereby the instrument is set for a given voltage. Adjustment of the pressure throughout a wide range is quite easy and thus provides practically any desired range of voltage value. In this way values of air density which necessitate a troublesome correction at atmospheric pressure, are eliminated, and in fact, are turned to account in providing a ready means of extending the scale of the instrument. One wire or rod serves for the whole range, and no adjustments other than that of the pressure are necessary. There is in fact, no limit to the range other than that due to the insulation of the air tight bushings, through which connection is made to the corona forming rod, and that set by a safe gas pressure within the instrument. In the two forms of instrument described below, in the smaller a working range between 20,000 and 50,000 volts is obtained with a pressure of 30 cm. below, and 60 cm. of mercury above, atmospheric pressure. A corresponding range with 100,000 volts as a maximum and the same range of pressure is obtained in the larger instrument.

Description of Voltmeters

100,000-volt type

The first type, designed after a number of preliminary experiments, for a range of 100,000 volts is shown in Fig. 1. It consists of an outer steel shell 45.7 cm. outside diameter and 44.4 cm. inside diameter. The ends are enclosed with plate glass disks 1.9 cm. thick, held between flanges, and each supporting

in a hole in its center a 100,000-volt porcelain bushing. This outer shell provides a chamber in which the pressure may be varied; the voltmeter proper is inside. The picture shows some of the various terminals and auxiliary apparatus. The length of the outer shell over flanges is 190 cm. The length of the whole instrument over insulator bushings is 238 cm.

Fig. 2 is a descriptive drawing showing the various parts. In order that certain features may be emphasized no attempt has been made to make the drawing to a uniform scale. The central conductor on which corona is formed, shown at *A*, consists of about 40 in. (101.5 cm.) of Stubb's tool steel, 0.635 cm. in diameter. At either end, just outside the cylinder *B*, the central conductor is suitably joined to rods of larger diameter which extend through the porcelain bushing *E* at either end. The object of this enlargement is to make certain that the electric

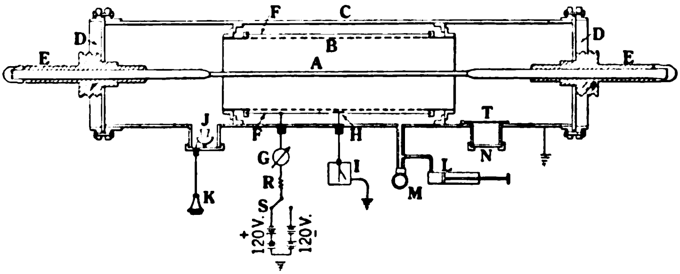
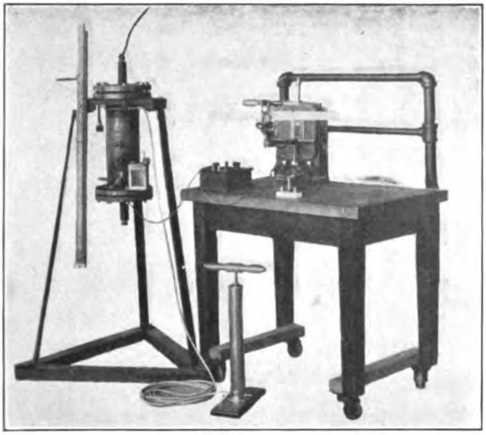
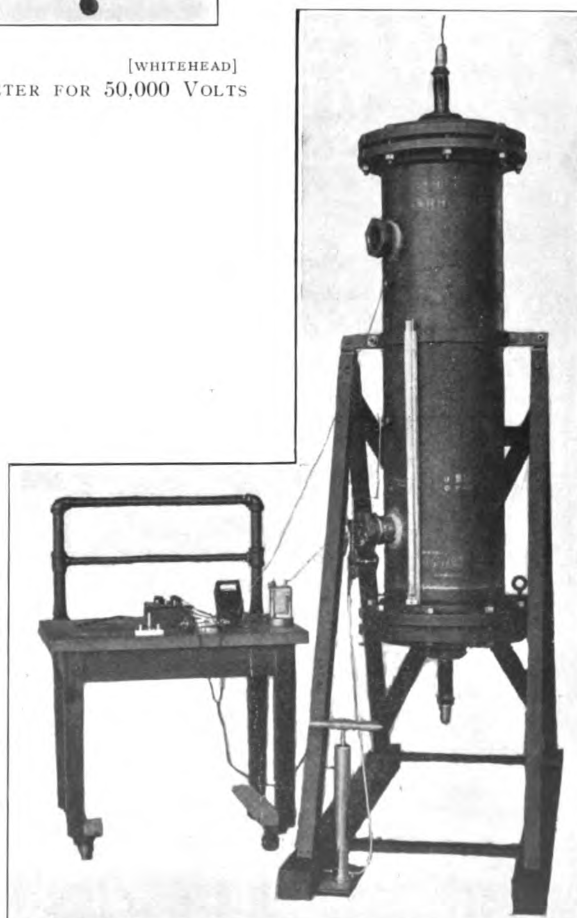


Fig. 2—Corona Voltmeter for 100,000 Volts—Central Section and Connections of Auxiliary Apparatus

discharge occurs only within the region inside cylinder *B*. This outer cylinder *B* is 92 cm. long, 30.7 cm. in diameter, is perforated over its entire surface with holes 1.58 cm. in diameter, and is electrically connected to the outer shell *C*, which is in turn connected to earth. The insulators *E* are cemented to the glass disks *D*, which in turn are held between soft rubber gaskets and the flanges on the outer tube. The final centering of the central conductor is accomplished at the ends of the insulators, the central openings of which provide free play for this purpose. *F* is a thin metal cylinder surrounding, and very close to, the perforated cylinder *B*. It is insulated and connects through a sulphur bushing with the galvanometer *G* and a source of continuous potential *S*. *H* is a small electrode fitting in a hole in *F* but not touching it, and connected through a sulphur bushing with an electroscope, *I*, whose case is connected to earth. *J* is



[WHITEHEAD]
FIG. 3—CORONA VOLTMETER FOR 50,000 VOLTS



[WHITEHEAD]
FIG. 1—CORONA VOLTMETER FOR 100,000 VOLTS

a telephone transmitter fitting into a side tube shown in Fig. 1. *L* is an ordinary hand air pump for either pressure or vacuum; together with the gauge *M* it is connected to the main containing cylinder. *N* is a small side tube with glass top through which the thermometer *T*, recording temperature inside the tube, may be observed. All permanent joints were sealed with a cement made from litharge and glycerine, while those holding the glass and cap nuts on the end of the central conductor consisted of soft rubber gaskets. No particular care was given to the elimination of unnecessary joints, and it has been found possible to maintain pressure as high as 60 cm. above atmosphere over periods quite sufficient to insure constancy of observation.

In designing the instrument as described above, liberal allowances were made in all dimensions. It was the first instrument in which pressure was applied and in order to provide also for thorough inspection and access to all parts, it was realized that it would probably be found unnecessarily large. This proved to be the case. The indications of the appearance of corona by the several methods already described were so satisfactory that it was soon found that the instrument could be made smaller without sacrifice of reliability.

The only limitation which has been found in this first type of instrument is in the insulation. If too large a central conductor is used, say above 1.75 cm. diameter, the high voltage required to start corona causes a spark between the conductor and the outer casing at the edge of the insulator bushing due to a region of high electric intensity. This trouble is entirely eliminated by the use of a smaller corona conductor, with ends of larger diameter, as already described. Corona then appears at lower voltages at atmospheric pressure and the spark-over voltages at the bushing are never reached. The voltage at that point only rises when pressure is on the tube and sparking is then suppressed.

The pressure in this tube has only been carried to 62 cm. of mercury. This means a total thrust of 2100 lb. (952.5 kg.) on each end of the plate glass disks at the end. While the central conductor can probably be relied on to take up a part of this thrust the pressure has not been carried higher up to this time for fear of breaking the glass disks. It is not necessary to have the whole end of the tube of glass, as small openings only are required for observing visually, the appearance of corona. Therefore, in a tube of the general dimensions given, it should be quite

easy to reach pressures far in excess of that mentioned. Our experience indicates that the chief limitation of the instrument is the insulation of the bushing leading the voltage to the central corona forming conductor.

50,000-VOLT TYPE

As a result of the experiments with the foregoing instrument, another was designed for 50,000 volts in which effort was made to reduce the dimensions without impairing its reliability. Fig. 3 shows a general view. In all respects the details of the instrument are the same as those already described in connection with the larger type, except that is this smaller type the telephone has been omitted. This was done largely because of the difficulty and time required for setting into the outer cylinder a branch tube large enough to hold the telephone transmitter, the diameter of the main cylinder being only 12.7 cm. Observations are in no wise dependent on the use of the telephone and this was not considered as a necessary feature for an experimental type of instrument.

The principal dimensions for the smaller instrument are as follows: Outer tube, 12 cm. inside diameter, 24 cm. diameter over end flanges, length over flanges, 52 cm., length over all, 76 cm. The inside or corona tube is 9.51 cm. inside diameter and 29 cm. long. Central conductors or rods of various diameters have been used. In the experiments described below the rod was of tool steel, 0.396 cm. in diameter.

In this instrument as in the other, the limit has been found in the insulation of the end bushings. In the form shown, brush discharge begins at 65,000 volts over the inside surface of the glass ends. As the insulators were home-made, by making the whole instrument somewhat longer, and improving the insulation, there seems to be no reason why this instrument could not be used for even higher values. The pressure required to reach above 50,000 volts was only 66 cm. of mercury above atmosphere.

Pressure is adjusted and varied in the tubes without trouble by means of an ordinary hand pump, for both vacuum and pressure, about 46 cm. long, and of the type used for bicycle and automobile tires. A valve with small opening permits easy adjustment of pressure.

OBSERVATIONS AND TESTS

Power was taken from a 10-kv-a., 100,000-volt transformer fed by a 7.5-kv-a., motor-driven, smooth body, surface-wound,

single-phase generator, specially designed to give a smooth wave. The set was designed for frequencies between 45 and 120 cycles and was equipped for close speed and generator field control within wide ranges.

Throughout the experiments a frequency of 60 cycles was maintained. Variation of the transformer primary voltage was accomplished by varying the field current of the generator.

The transformer is of the core-type, having all of its coils wound on one side of the magnetic circuit of rectangular shape. It is provided with two primary coils, each for 110 volts. It also has a tertiary coil with the same number of turns as one primary coil. All of these coils are close to the core. The high-tension winding consists of a large number of pan-cake shaped coils set side by side over the primary and filling a large portion of the central opening of the magnetic circuit. The transformer was designed for operation at any frequency between 20 and 120 cycles. The ratio of high-tension to tertiary coil turns is 833.36.

All observations have been made with the outer tube of the voltmeter, one end of the tertiary coil, one end of the primary and one end of the high-tension winding all connected to ground. In the observations of the smaller voltmeter the primary coils were connected in series while on the larger they were in parallel The value of the generator voltage in both cases ranged from 20 volts up to about 100. It will be seen therefore that all observations were taken at comparatively low values of the magnetic density in both the generator and transformer. Power for the direct-current motor and also for the generator field was taken from a storage battery, giving most of the time practically perfect conditions as to constancy.

The general method of taking observations was, with secondary connected to the central conductor of the voltmeter, to raise the voltage gradually, observing the electroscope and galvanometer, and listening with the telephones, singly or all together Simultaneous readings of all three were possible by using a reflecting galvanometer, and throwing, with suitable mirror arrangements, the image of the electroscope leaf into the telescope used for reading the galvanometer. As soon as any one or all of the instruments indicated the appearance of corona the voltage was read by an electro-dynamometer type of voltmeter on the terminals of the tertiary coil of the transformer. A large number of oscillograms were taken during the course of the experiments which, with the voltmeter readings, serve to give the crest factors of the voltages in the tertiary coil.

Special interest attaches to the extreme constancy with which the corona is indicated by any one of the four methods described and to the closeness with which the four methods agree among themselves.

The readings in Table I were taken by two observers. One observer would read the electroscope or galvanometer or listen with the telephone while gradually raising the voltage. As soon as indication of corona appeared he would tell the other observer to read the voltage. The voltage would then be lowered by an indeterminate amount and the process repeated. The readings with each type of indicating instrument were taken singly, the several sets following one immediately after the other.

As a general thing the electroscope leaf would stand apparently perfectly still, its normal rate of leakage being extremely

TABLE I.

COMPARISON OF ELECTROSCOPE, GALVANOMETER, AND TELEPHONE AS INDICATORS OF PRESENCE OF CORONA

	Critical volts on tertiary coil. 0.633 cm. diam. rod in 30.7 cm. tube					
Electroscope.......	48.75	48.75	48.8	48.8	48.75	48.75
Galvanometer. ...	48.8	48.8	48.75	48.8	48.75	48.7
Telephone.........	48.8	48.8	48.75	48.8	48.8	48.75

small. With the appearance of corona the leaf would discharge in periods varying between one and five or six seconds depending upon the size of the conductor and the condition of its surface. The rate of leak attendant upon the appearance of corona is always sharply marked, and there is no difficulty in distinguishing it even when at its slowest.

The galvanometer deflection is also sharply marked. With the approach to corona voltage the galvanometer stands at zero or with a small deflection due to leakage over the insulation of its electrode, the deflection being practically constant. With the appearance of corona the galvanometer takes a sharp increase of deflection the amount of which is dependent upon its sensitivity. In the mirror galvanometer already mentioned, the amount of this sudden deflection was 6.5 mm. No fine adjustment of the voltage increase could bring the deflection

below this value. With the less sensitive needle galvanometer already described, the deflection was considerably less of the order of one mm. which, however, is readily detectable. These deflections increase rapidly with even a small increase of the voltage above the corona forming point.

With reference to the telephone, it has already been stated that with the approach to corona voltage there is no sound in the telephone, but the instant corona appears a very pronounced note is heard.

A number of preliminary tests with various sizes of central conductor were made on each type of voltmeter. These tests had as their principal object the study as to how the values obtained would agree with the formulae given by various exper-

TABLE II.

COMPARISON OF OBSERVED AND CALCULATED CORONA VOLTAGES

Diam. rod cm.	Critical volts			δ	Critical surface intensity	
					Obs.	Calc.
0.238	21.6	21.7	21.8	1.014	59,400	59,800
0.317	24.6	24.7	24.6	1.014	55,500	55,400
0.396	27.6	27.6	27.6	1.017	53.800	54,000
0.477	30	30	29.9	1.017	50,700	51,200

iments connecting the critical surface intensity of a conductor with its diameter and with the temperature and pressure.

The method followed in these tests has been the same as that used by one of the authors in his papers on "The Electric Strength of Air." This method involves the reading of the critical voltage on the low-tension side, the measurement of the wave form on the low-tension side, and the assumption that the ratio of transformation of the transformer is that of the number of turns in primary and secondary. This method has been found to give very uniform results for moderate values of the secondary voltage.

Table II shows the results with four sizes of rod in the smaller voltmeter. The results calculated from the expression for the surface intensity,

$$E = 32\left(\delta + 0.296\sqrt{\frac{\delta}{r}}\right) \text{ kv/cm.} \qquad (1)$$

are also given in one column of the table. It will be seen that the agreement is quite close. The constants of the above expression are those which were first proposed by one of the authors. Peek's corresponding expression gives a value in the neighborhood of 31 instead of 32 for the principal factor of the right hand member of the expression. Further evidence, leading to the conclusion that the higher value is the correct one, is given in our results below in which the density of the air is varied through wide limits.

A number of tests were also taken with various sizes of central conductor in the larger voltmeter. The observations were taken under the same conditions of accuracy and care, and could also be repeated as often as desired. The values of voltages, however, as read on the low-tension side, and reduced to the high-tension side in the method described, were always lower than the values calculated from the expression given above. This discrepancy was found to be due to a rise in voltage in the secondary circuit, owing to its leakage reactance and to the charging current of the larger voltmeter, this rise having no equivalent in the tertiary coil.

The primary current of the transformer increased from 2.9 to 4.3 amperes on connecting the larger voltmeter, the power input of the primary remaining practically unchanged. The arrangement of the coils in the transformer has already been described and indicates clearly the probability of leakage reactance in the high-tension winding which has no counterpart in the tertiary coil on which the voltage was read.

Calibration

The calibration of any of the types of instrument heretofore used for measuring crest voltages has always been an uncertain factor. The usual method has been comparison with a standard needle or sphere gap, or with low voltage voltmeter readings corrected for crest factors. But, as is well known, both types of spark-gap must themselves be calibrated, since it is not certain that even the sphere gap will break down at a voltage which can be calculated in terms of the separation and the diameter of the spheres. It is now stated, with considerable confidence, that a tertiary coil can be so wound in a high-tension transformer that it will reflect accurately the value and wave form of the voltage in the high-tension winding. While this may be true, the evidence is still lacking, and the reason is that there is

no certain method of measuring the high-tension voltage directly in terms of laboratory standards.

It is the opinion of the authors of this paper that the desired standard of voltage for values above 10,000 or 15,000 is available in the corona forming on a clean wire centered in an outer cylinder. All observers are now agreed that corona forming voltages repeat themselves with the greatest degree of accuracy under the same conditions of temperature and pressure, and further, the variations due to temperature and pressure are now understood. The constants which give the actual value of critical corona voltage for a given size wire as determined by different observers, agree very closely. It would appear then, that the only thing necessary to fix an absolute standard of high voltage is the formation of a committee who should conduct, under properly considered conditions, a series of experiments for the determination of the figure for the electric strength of air which could be used as a standard. This quantity is undoubtedly a definite physical constant, and it is only necessary to eliminate all source of error in experiment to determine it accurately.

The corona voltmeter as already described, can of course, be calibrated by exactly the same means which are used for the calibration of the standard spark-gaps. In view, however, of the uncertainty of such calibration, the authors have preferred to compare the indications of the instruments with values of corona forming voltage as deduced from formula (**1**), in which E is the electric intensity at the surface of the wire, at which corona is formed, in kilovolts per centimeter, and δ is the density factor given by the expression

$$\delta = \frac{3.92 \times p}{273 \times t} \qquad (2)$$

in which p is the pressure in cm. of mercury, and t is the temperature in centigrade degrees. The constants of formula (**1**) have been checked a number of times by one of the authors. The values found by Peek and others are in close agreement.

50,000-*Volt Type.* In Table III, are given the results of a series of observations with varying pressures on the smaller type of voltmeter. The readings taken were: voltage on the tertiary coil, air pressure, as measured on a mercury pressure gauge, temperature inside the tube, and oscillograms of the tertiary coil voltage in order to obtain the crest factors. The oscillograms have an average amplitude of 2.2 cm., and a length

at the base of about three cm. The ordinates were measured at distances of one mm. As so measured, the crest factors varied uniformly between 1.455 and 1.442, over a range of tertiary coil voltage from 20 to 45 volts covering the range of observation.

The values of the corona surface intensity, as observed and also as calculated from the expression given above are given in the last two columns of the table. In Fig. 4 a curve is drawn between the critical surface intensity and the density factor. The solid curve gives the relation as calculated, and observed values are indicated by crosses. It will be observed that at higher values of pressure the observed values are slightly lower

TABLE III.

OBSERVATIONS WITH 50,000 VOLTS CORONA VOLTMETER

Pressure cm.		Temp. deg. cent.	δ	Ter. Coil volts		Crit. surf. intens. volts per cm.		Max. volts
Obs.	Corr.			Eff.	Max.	Obs.	Calc.	
− 34	43.5	27	0.569	17.8	25.9	34,390	34,200	21,580
− 33	44.5	27	0.581	18.	26.2	34,760	34,800	
− 32.8	44.7	27	0.581	18.2	26.4	35,120	34,940	....
− 26.9	50.6	27	0.661	20.	29.1	38,600	38,450	....
− 26.4	51.1	26.5	0.668	20	29.1	38,600	38,750	24,200
− 25.8	51.7	26.5	0.676	20.3	29.5	39,150	39,120	....
− 17.5	60	26.5	0.785	22.8	33.1	43,920	43,760	....
− 17.2	60.3	26.5	0.789	22.8	33.1	43,920	43,920	....
− 17.	60.5	26.5	0.791	22.9	33.2	44,140	44,000	27,700
− 11.8	65.7	26.	0.861	24.4	35.4	47,000	47,300	....
0.	74.7	26.	0.979	27.	39.1	51,950	52,350	....
0.	74.7	20.5	0.997	27.5	39.8	52,900	53,150	....
+ 15.	86.9	20.5	1.160	30.7	44.5	59,020	60,050	37,100
15.3	87.2	20.5	1.164	30.8	44.6	59,220	60,200	....
25.2	97.1	21.	1.294	33.7	48.8	64,750	65,600	....
26.3	98.2	21.	1.309	34.	49.2	65,350	66,200	....
27.7	99.6	21.	1.327	34.4	49.8	66,050	66,900	41,500
33.4	105.3	22.	1.4	35.9	51.9	68,900	69,900	....
34.2	106.1	22.	1.410	36.2	52.3	69,400	70,000	....
38.3	110.2	23.	1.460	37.3	53.9	71,600	72,400	....
38.9	110.8	23.	1.468	37.5	54.2	71,900	72,700	45,100
45.1	117.	23.	1.549	39.2	56.6	75,200	76,000	....
45.9	117.8	23.	1.560	39.5	57.0	75,700	76,400	....
53.1	125.	24.	1.650	41.5	59.9	79,500	80,100	....
54.2	126.1	24.	1.664	41.8	60.3	80,050	80,700	50,300
56.7	128.6	24.	1.697	42.2	60.9	80,800	82,000	....
60.7	132.6	25.	1.744	43.5	62.7	83,250	83,800	....
61.9	133.8	25.	1.760	43.6	62.9	83,480	84,500	....
63.3	135.2	25.	1.778	44.0	63.4	84,700	85,200	52,800
66.	137.9	26.	1.807	44.8	64.6	85,700	86,400	53,800

than those calculated. This is partly due to the fact that the observations were taken with very slowly-diminishing pressure owing to leaks in the tube. Much time and trouble was saved by closing some of the necessary openings in the tube with rubber gaskets instead of sealing them permanently. These gaskets leaked slowly at the high pressures. It is also possible that a rise in secondary voltage due to leakage reactance and charging current was present at the higher values of voltage.

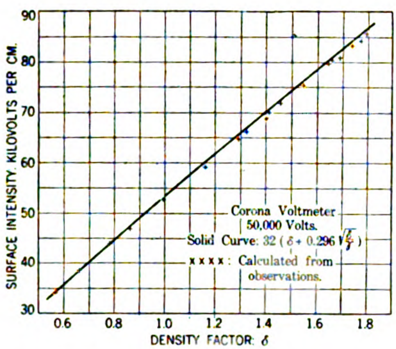


FIG. 4—CALCULATED AND OBSERVED VALUES OF VOLTAGE AT DIFFERENT VALUES OF AIR DENSITY

100,000-*Volt Type.* The larger type of instrument has been operated with a number of different sizes of central conductor and through the range of pressure between 65 cm. and 136 cm. of mercury corresponding to a range of voltage between 50,000 and 110,000 maximum values. Table IV gives a typical series of observations with a steel rod 0.635 cm. in diameter as the central conductor. The table also contains a column giving the values calculated from the expression for the critical surface intensity as affected by temperature and pressure to which

TABLE IV.
OBSERVATIONS WITH 100,000 VOLT CORONA VOLTMETER

Pressure cm.		Temp. deg. cent.	δ	Ter. coil volts		Crit. surf. intens. volts per cm.		Max. volts
Obs.	Corr.			Eff.	Max.	Obs.	calc.	
− 10.6	64.7	21.7	0.861	40.5	60.7	41,300	43,150	50,600
− 6.4	68.9	21.7	0.918	42.4	63.5	43,250	45,450	53,000
− 5.8	68.9	20.8	0.920	42.9	64.3	43,750	45,500	53,600
0.	74.7	20.7	0.996	45.9	68.8	46,800	48,650	57,400
+ 6.	80.7	20.9	1.076	48.6	73.0	49,580	51,800	60,800
11.3	86.0	21.	1.146	51.1	76.6	52,120	54,650	64,000
16.2	91.0	21.1	1.212	53.4	80.8	54,450	57,400	66,700
21.1	96.0	21.2	1.278	55.7	83.5	56,820	59,850	69,600
27.6	102.5	21.3	1.365	58.4	82.7	59,600	63,300	73,000
33.9	109.0	21.4	1.451	61.1	91.6	62,320	66,550	76,400
37.7	112.8	21.5	1.502	62.9	94.2	64,150	68,600	78,600
43.3	118.5	21.6	1.576	64.3	96.5	65,700	71,350	80,300
48.2	123.5	21.7	1.643	65.9	98.7	67,200	74,050	82,400
55.7	131.0	21.8	1.742	68.5	102.8	69,800	77,900	85,600
61.4	136.7	21.9	1.818	70.8	106.1	72,100	80,800	88,500

reference has already been made. The curves of Fig. 5 show the relation between the critical surface intensity and air density as calculated from formula (**1**) and also values as estimated from the readings of the voltmeter on the tertiary coil.

As will be noted, with ascending values of air density and therefore critical voltage, there is an increasing difference between the values calculated from formula (**1**), and those estimated from the low-voltage readings. As stated earlier in the paper, the explanation lies in a voltage rise due to charging current taken by the capacity of the larger corona voltmeter, and the leakage reactance of the high-tension winding of the transformer, which is not proportionally reflected in the voltage at the terminals of the tertiary coil. The amount of this rise would evidently be greater, the greater the value of the charging current of the voltmeter tube; that is, the higher the value of the impressed voltage. The curve of the observed values, therefore, shows values lower than those actually reached at the high-tension terminals. In the case of the 50,000-volt instrument, owing to the very much smaller capacity, this influence, if present at all, was scarcely noticeable.

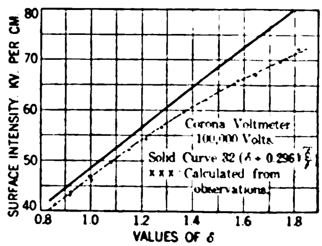


FIG. 5 — COMPARISON OF VOLTAGE AS INDICATED BY READING ON TERTIARY COIL WITH CALCULATED VALUES AT DIFFERENT DENSITIES OF AIR

The above results, therefore, with the larger instrument are not to be considered as an attempt at calibration. They show rather, that in applying a range of voltage and pressure to the instrument to test its value, a method which has been commonly relied on for indicating high-tension voltages in transformers is revealed as subject to large error. In fact, the observations as taken constitute a conspicuous example of the value of the corona voltmeter in checking the ratio of transformation between the tertiary coil and the high-tension winding of a transformer. The only open question is the accuracy of formula (**1**), and this formula, both as to the value of its constants, and the form in which the values are related, is agreed upon with only slight divergence among many experimenters.

Aside from all question of the accuracy of the above deductions the instrument has been carried through a range of voltage between 50,000 and 100,000 volts. Particular values of voltage

as indicated by the instrument on the low-tension side, and by the appearance of corona, may be repeated as often as desired within a fraction of one per cent. If a suitable method of calibration can be devised, a calibration curve between the voltage and pressure may be drawn giving an absolute calibration of the instrument in terms of pressure and temperature.

Method of Measurement of Voltage

The instrument is susceptible of usage in two ways. (1) It may be set for a given voltage and the applied voltage gradually raised until the desired value is reached, as indicated by the instrument, or (2) with an unknown voltage applied to the terminals, the pressure in the tube may be gradually lowered until corona appears.

The first of these methods would be that commonly used in the testing of insulation. In applying this method the necessary operations are as follows: Read the temperature in the corona tube, take from a table or curve, calculated from the dimensions of the instrument, the value of pressure which, with the observed temperature, corresponds to the voltage required. Adjust the pressure to this value by means of a hand pressure and vacuum pump. Gradually raise the voltage from some lower value until the presence of corona is indicated by one of the methods already described.

Table V gives the values of pressure for the 50,000-volt instrument for voltages between 20,000 and 50,000 at temperatures between 10 deg. and 30 deg. cent. The values have been calculated as follows:

The inner tube having a diameter 9.51 cm., and the central rod a diameter of 0.396 cm., it may readily be shown that for a difference of potential V between the central conductor and the outer tube, the electric intensity at the surface of the central conductor is 1.593 V. The critical corona forming surface intensity as calculated is $32\,(\delta + 0.665\sqrt{\delta})$. Equating the two expressions and giving V any desired value, we obtain corresponding values of δ. Formula (**2**) gives the value of δ. Since p is the pressure in centimeters of mercury and t is the temperature in centigrade degrees, we at once obtain for any observed temperature, a pressure to which the tube may be adjusted in order to show corona at the particular voltage V for which p has been calculated. Obviously a series of curves can be drawn to take the place of the table if desired.

TABLE V.

PRESSURES IN CM. MERCURY, AT WHICH 50,000 VOLT CORONA VOLTMETER MUST BE SET TO INDICATE VARIOUS VALUES OF VOLTAGE AT DIFFERENT TEMPERATURES

Max. volts	Temperature, degrees centigrade																
	10°	15°	16°	17°	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°
20,000	37.2	37.8	38.0	38.1	38.2	38.4	38.5	38.6	38.7	38.9	39.0	39.2	39.3	39.4	39.5	39.7	39.8
25,000	49.8	50.7	50.9	51.0	51.2	51.4	51.6	51.8	52.0	52.1	52.3	52.5	52.7	52.8	53.0	53.2	53.3
30,000	63.0	64.2	64.4	64.6	64.8	65.1	65.3	65.5	65.7	66.0	66.2	66.4	66.[illegible]	66.8	67.1	67.3	67.5
35,000	76.2	77.5	77.8	78.0	78.3	78.6	78.9	79.2	79.4	79.7	80.0	80.2	80.5	80.8	81.0	81.3	81.6
40,000	90.3	91.9	92.2	92.6	92.8	93.2	93.5	93.8	94.2	94.5	94.8	95.1	95.4	95.7	96.0	96.4	96.7
45,000	103.8	105.7	106.0	106.4	106.8	107.2	107.5	107.9	108.2	108.7	109.0	109.3	109.7	110.0	110.4	110.8	111.2
50,000	118.1	120.2	120.6	121.0	121.4	121.9	122.3	122.8	123.2	123.6	124.0	124.4	124.8	125.2	125.6	126.0	126.5

In the second method mentioned, in which it is desired to measure the value of an unknown voltage, it is only necessary to run the pressure in the tube up to a value corresponding to a voltage known to be above that to be measured. The pressure may then be lowered rapidly by allowing the air to escape until corona appears. Having approximated the voltage by this means the pressure may be raised again above the value at which corona appears and then lowered as gradually as desirable in order to establish any particular degree of accuracy of observation. The table of pressures as described above may also be used in this case. In using this method it is inadvisable to lower the pressure by any considerable amount below the corona forming pressure. If this is done the volume of corona increases greatly, which may result in spark-over, and which if allowed to continue will make it necessary to clean the surface of the central conductor.

Pressures may be read if necessary on an ordinary mercury gage. If this is done it is also necessary to read the actual value of the atmospheric pressure. However, pressure gages are available which read absolute pressure directly, thus obviating the necessity of making the additional observation of atmospheric pressure.

Permanence of Calibration

It is well known that the condition of the surface of the central conductor as regards inequalities has an important bearing on the sharpness with which corona will appear. Small specks of dirt cause regions of high electric intensity which form sparks or point discharges at voltages below that corresponding to corona for the smooth conductor. In the use of the instrument as described, therefore, it is important that the central conductor should be carefully cleaned before insertion into the outer tube.

No special difficulty is met in so cleaning the surface of the wire that no preliminary sparks appear and so that the appearance of corona is not only sharply marked but may be repeated many times without a variation in the value of the corresponding voltage.

Time Tests. In order to test the possibility of the repetition of the readings, a series of observations were taken on a voltmeter differing some-what from those described, extending over a period of five months. This voltmeter was open to the air and subjected only to atmospheric variations of the density.

Readings of the corona voltage were taken four or five times a week throughout the period, and showed when corrected for temperature and pressure a maximum deviation of six-tenths of one per cent from the calculated value. In this series of observations the wire was cleaned every day or two.

Permanence of Surface. In order to determine whether, and to what extent, the surface of the wire deteriorates with use, a number of tests were conducted on brass, nickel, and silver plated rods in addition to copper and steel rods commonly used. These tests consisted of the running of the instrument continuously with voltage slightly above the corona forming voltage, interrupting the run at intervals to see to what extent if any, the observed corona voltage had been lowered. One per cent excess voltage will result in a well formed corona, while five per cent excess gives one of marked volume and sound. The results were as follows:

Brass rod, 0.234 cm. diameter, primary voltage at start 61.2; run for 44 minutes at one per cent excess voltage with a number of intermediate readings. Corona voltage at end of test 61 volts, a change of about one-third of one per cent.

Nickel plated rod, 0.24 cm. diameter, voltage at start 61.5, run for 48 minutes, at one per cent excess voltage with intermediate readings, voltage at end 61.1 volts a decrease of less than two-thirds of one per cent.

Silver plated rod, 0.24 cm. diameter, corona voltage at start 61.5, run for 42 minutes and from one to 5 per cent excess voltage, with intermediate readings; corona voltage at end of test 61.5 volts, thus showing no deterioration.

The lowering of corona-forming voltage in the first two of these wires is in a great measure accounted for by the elevation in temperature in the tube due to the presence of corona and is not all due to deterioration of the surface. Thus in the case of the brass wire the temperature rose during the test from 23.9 to 25.2 deg. In the case of the nickel rod the temperature rose from 25.4 to 26.5 deg. In the case of the silver rod the rise in temperature was only from 26.9 to 27.3 deg. The conclusion from these tests therefore, is that the life of any polished conductor for the purpose of observing corona should be quite long for any meterial which does not oxidize freely in the air.

It is quite obvious that the design of the corona voltmeter as already described, permits the ready removal of the central conductor in case it should be suspected that the surface is not

clean. The use of the telephone as a detector indicates very promptly the presence of any single points of discharge, such points having a characteristic sound in the telephone which is quite different and of a very much lower intensity than that corresponding to full corona.

Dimensions

The dimensions of the corona voltmeter are apparently determined by three factors; the diameter of the corona tube, the length of this tube, and the requirements of insulation of the connection to the central conductor where it passes through the ends of the outer or pressure cylinder.

The diameter of the corona tube is largely determined by the maximum voltage. It has a simple well-known relation to the diameter of the inside conductor for any particular value of corona forming voltage. The most advantageous relation of these two diameters has not yet been determined. For example, no direct study has been made of the increase that is possible in the diameter of the central conductor before the formation of corona is coincident with that of spark-over. For smaller sizes of conductor it is possible to raise the voltage by considerable amount above that at which corona starts without resulting spark-over. With increasing diameter of conductor, however, this possible range above corona voltage becomes narrower. From a number of indirect observations, the present experiments seem to indicate that a ratio of diameters of the inner conductor to outer cylinder greater than 0.1 is apt to be attended by spark-over. These observations have largely determined the sizes of central conductor which have been used in the two instruments described above.

The length of the interior or corona cylinder may be considerably less in each case than those adopted in the two types of instrument as described. In order to determine the length absolutely necessary a number of experiments have been made on tubes of the same diameter but of varying lengths, under atmospheric conditions. With tubes 6.35 cm. in diameter and rods 0.317 cm. in diameter, observations of corona voltage were made with tubes of lengths four, two, one and five tenths, and one diameters in length. The observations show that with decreasing length there was no perceptible rise in the corona voltage until two diameters of length was reached. For this length there was an apparent rise in the corona voltage of about

one-half of one per cent; for one and one-half diameters a rise of about one per cent, and for one diameter of length corona voltage was about three per cent higher than for tubes of lengths four or more diameters.

It should be noted, however, that the use of the galvanometer as indicating instrument requires a longer inner tube in order to make available a sufficient amount of ionization for the deflection of an instrument of ordinary sensitivity. There are obvious advantages in the use of a galvanometer, and it is our opinion that on this account it is not advisable to attempt a corona tube shorter than three diameters.

The requirements of insulation of the leading-in conductors add the greatest proportion to the length required for the whole instrument. The conditions here are much the same as at the leading-in terminal bushings of a transformer. The inner end of such a bushing can be brought fairly close to the inside cylinder but must not disturb the distribution of the electric field within that cylinder nor introduce any regions of higher intensity outside the cylinder.

The observations on the two instruments as described indicate that it would not be possible to reduce the dimensions of the smaller type without limiting its range. The larger type, however, is unnecessarily large in every direction. The outer cylinder can be reduced somewhat in diameter as can also its length without modification of the interior corona cylinder and central conductor. The interior cylinder can also be reduced somewhat in length without seriously inpairing the accuracy of the reading of the indicating instrument. Apparently it should be possible to construct a corona voltmeter for 100,000 volts with an over all length of about two meters and a maximum outside diameter of 45 to 50 cm.

The question of the extreme reduction of the dimensions of instrument as well as that of direct calibration, can only be determined by further investigation. It is the hope of the authors to carry forward such investigations. The present paper has as its principal object to show that it is possible to construct and operate a voltmeter based on the corona principle, which possesses an absolute calibration, a wide range, a high degree of constancy, and several other advantages over existing instruments for the reading of high voltage. Thanks are extended to Dr. W. B. Kouwenhoven and Mr. W. S. Brown for their assistance with the oscillograms and in other particulars throughout the work.

SUMMARY

The following conclusions seem to be justified by the experiments which have been described:

1. An instrument making use of the appearance of corona as an indication of the maximum value of alternating voltage has been devised and constructed in two sizes for ranges 20,000 to 50,000 volts and 40,000 to 100,000 volts respectively.

2. The principle of operation depends on a natural constant and the calibration of the instrument is definitely determined by its dimensions. This calibration may be supplemented by calibration with any existing standards.

3. In setting for different voltages no alterations in dimensions nor other manipulation is necessary. Variations in setting require changes in air pressure only. The necessary changes may be effected with a hand pump.

4. Three, and if necessary, four means of observing the indications of the instrument are described. They may be used simultaneously, thus serving as checks upon each other.

5. No spark-over, nor arc, nor energy consumption occurs in the operation of the instrument.

6. No series resistance nor condensers are necessary to its operation.

7. Observations may be repeated rapidly and any number may be taken with one setting.

8. The calibration is within wide limits, independent of wave form and frequency. It is also independent of electrostatic influence of neighboring conductors and objects.

9. It is readily constructed in portable form.

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To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

STUDIES IN LIGHTNING PROTECTION ON 4000 VOLT CIRCUITS

BY D. W. ROPER

ABSTRACT OF PAPER

Investigations forming the basis of the paper have been carried on for a period of five years. They were made on a system which at present supplies service to 250,000 customers over some 3000 miles of circuit, through about 16,000 transformers. During the experiments a number of theories have been tried out in practise and the results of the experiments are given in some detail. At the beginning of 1915, three distinct types of arresters and three schemes of protection were in use. The conditions during the year 1915 and the records obtained from lightning storms during the year are set forth by means of a number of maps, drawings and tables. An analysis of the results is followed by a list of conclusions.

The several methods of improving the lightning protection have together resulted in eliminating over 90 per cent of the troubles from lightning.

I—DESCRIPTION OF THE SYSTEM

THE DISTRIBUTING system on which the investigations herein contained were made, covers about 180 square miles in the city of Chicago, and supplies about 250,000 customers through about 16,000 transformers. During the five years covered by these studies, the load has increased from 28,600 kw. to 73,900 kw. The system of distribution is four-wire, three-phase, with 2400 volts (nominally) between each phase wire and the neutral wire, the latter being grounded only at the sub-stations. The system is supplied by 125 feeders from 15 sub-stations, as shown in Fig. 1. All of the feeders leave the sub-stations in four-conductor underground cable, of which there are over 200 miles (321.8 km.) On the average the feeders extend, therefore, nearly two miles (3.2 km.) underground before connecting to the overhead lines, and the length of the overhead feeders is about 25 per cent of the total length. There are, roughly, 3000 miles (4828 km.) of primary distributing mains of which less than 10 per cent is underground. About 100 of the distributing transformers are located in manholes or in transformer vaults on the customers' premises. All of the

Manuscript of this paper was received April 24, 1916.

transformers are connected between the neutral wire and one phase wire, and in the three transformer three-phase installations there is no connection to the neutral wire of the circuit.

There were 15,605 transformers connected to the line on August 1st, 1915, and all of the percentages for that year were based on the records of transformers installed as of that date. A map of the city showing the distribution of transformers is shown in Fig. 2.

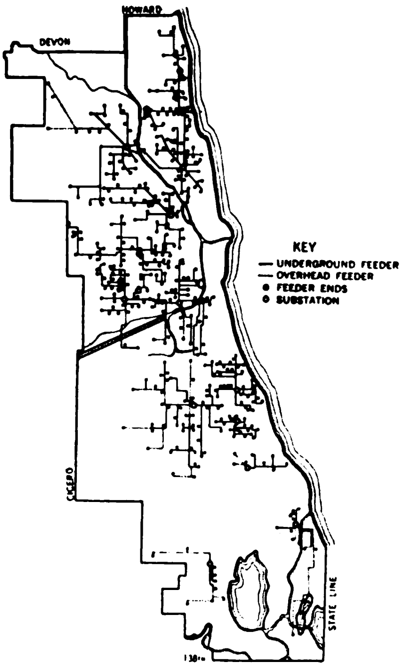


FIG. 1—MAP OF 4000-VOLT DISTRIBUTING FEEDERS IN CHICAGO

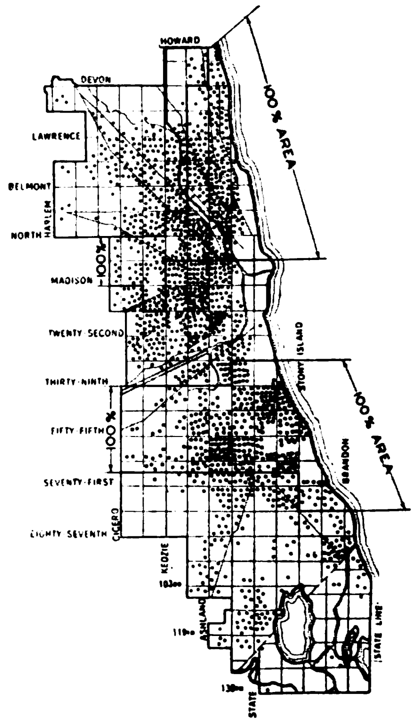


FIG. 2—TRANSFORMERS IN SERVICE IN 1915. EACH DOT REPRESENTS TEN TRANSFORMERS

II—PRELIMINARY STUDIES

As the object of the investigation was to improve the service a preliminary study was first made of all of the interruptions on the distribution system, which were classified according to their cause. This showed that transformer troubles were responsible for more interruptions to service than any other single item, and also that a large fraction of all transformer troubles

were primarily due to lightning. The need for further investigation of our lightning protection methods was, therefore, very apparent.

Upon requesting the purchasing agent to increase the size of the usual order for lightning arresters, he caused some embarrassment by inquiring what type of arrester had been shown by our experience to be best suited to our purposes. The only answer that could be given to this question was that the arresters had been selected in very much the same manner as our articles of clothing, that is, according to the type which was in fashion at the moment; and further, that the methods of installing the arresters had been such that it was quite impossible to tell from any operating records which arrester, if any, was the best. It was suggested, in the absence of definite information on the subject which would warrant a change in practise, that it seemed advisable to continue to buy arresters of each of the three types that were then in use. As it seemed quite important to determine, if possible, which was the best arrester, it was decided that such changes in the methods of installation should be made as would permit the keeping of records that would assist in securing the desired information.

III—Starting the Investigations

The first step in the investigation was to make a careful record of all transformer fuses blown by lightning during one severe storm. On the following day some of our best troublemen and linemen were sent out to examine carefully these transformers for signs of arcing which could have caused the blowing of the fuse, and in about 80 per cent of the cases the men were successful. Most of the signs indicated arcing on the primary terminal board between the terminals, or from the terminals to the cover. In a smaller number of instances, the arcing had occurred around the primary bushing either inside or outside of the transformers, or between the primary lead and the case. Investigating this matter further it was found that the repair shop had been omitting the terminal boards from all transformers which they rewound, or from those which were turned in with damaged terminal boards. Transformers altered in this manner were found to have a very excellent service record, and it therefore appeared that the advantages of the practise warranted further investigation. For this purpose one circuit was selected in 1911, to which were connected about 250 transformers, and all of the

smaller transformers were replaced by others which had their terminal boards removed. The removal of the terminal boards from the larger transformers was accomplished without removing them from the line. This work was completed so late in 1911 that no experience could be obtained during that year from the effects of lightning, and the installation remained without much change during 1912, except that care was taken to see that all additions or alterations to the circuit were made with transformers without terminal boards. No changes in the scheme of lightning protection in use previous to that time were made on this circuit, so that aside from the removal of terminal boards, this circuit was equipped in the same manner as the other circuits.

IV—Segregation of Lightning Arresters by Circuits

Previous to the time of starting these investigations, different types of arresters had been ordered in succeeding years, and the additional arresters were installed so as to protect the primary mains which had been extended during the previous year. The general plan was to locate the arresters so that there would be no transformer more than about 1000 ft. (304.8 m.) distant from the nearest arrester. Although this scheme of installation very thoroughly mixed the several types of arresters on the circuits, it was still quite possible to keep records of the failures of arresters so that it could readily be told which one was the greatest hazard to our system; but no information whatever could be secured regarding the relative merits of the several types of arresters as protective devices. In order to secure this information, the plan was therefore adopted of installing only one type of arrester on any one circuit, and a portion of the arresters were moved each year until the segregation of arresters by circuits was completed.

V—Lightning Arresters on Transformer Poles

At about the time that these investigations were started, the theory was advanced, that lightning arresters to be most effective should be on the transformer poles. For the purpose of verifying this theory, two circuits were selected early in 1912 on which there were about 300 transformers, and on each circuit an arrester was installed on the same pole with each transformer. A different type of arrester was used on the two circuits. For brevity this plan is hereafter called "100 per cent protection" and the areas are termed 100 per cent areas." This installation differed from our previous practise in that (1) the number of arresters

equaled the number of transformers instead of being only a small fraction of their number; (2) the arresters were placed on the transformer poles instead of on the line poles.

VI—Analysis of Results Obtained in 1912 and 1913

Late in the year 1912, a study was made of two of the most severe lightning storms which had occurred during the season in an endeavor to find a fair basis for the comparison of the several types of arresters. As the 100 per cent areas showed an almost entire absence of lightning trouble in these two storms, it was at first thought that the solution of the problem had been reached. To check the conclusion, a map of the city was prepared on which the 100 per cent areas were shown by colored pasters. Then the areas covered by other circuits on which there had been no trouble whatever during the same storms was shown by pasters of a different color. Upon completion of the map it was discovered that there were a number of areas, protected only by a few arresters on the line poles, which were entirely free from lightning trouble, some of them being located adjacent to the 100 per cent areas.

The records of this year, and the map with the pasters of several colors showing the circuits on which there was no trouble, indicated very plainly that it was quite impossible to definitely determine from the records, or from any subsequent examination on the ground, whether the freedom from trouble was due to the perfection of the protection or to absence of lightning, and no method has yet been discovered for overcoming the difficulty. The cause of the difficulty is the fact that, the only means available for determining the presence of lightning and its relative intensity, is by the phenomona that are to be reduced by means of the improved lightning protection; and that having installed the lightning arresters and discovered a reduction in the trouble, there is no means of telling how much trouble there would have been were the lightning arresters absent. For the same reason it is impossible to recognize a uniformly distributed lightning storm, should it occur, although such a storm would greatly simplify these investigations. An endeavor was made to secure an independent reference standard by consulting the records of the telephone company, but it was found that during the period covered by these investigations, they were rapidly replacing their overhead open wire construction with aerial cable, and that this change greatly reduced the amount of trouble on their lines during lightning storms.

As a result of the experience in 1912, it was decided that the scheme of installing the arresters on the transformer poles gave promise of beneficial results, and that in order to secure more reliable information regarding the relative merits of the several types of arresters, the 100 per cent areas should be enlarged by the addition of several circuits, each having but one type of arrester.

The information obtained from the circuit from which the terminal boards had been removed, was indefinite and not at all conclusive, due apparently, to the fact that a sufficient number of transformers were not included in the experiment. It was, therefore, decided to remove the terminal boards from a larger number of transformers, so that at the opening of the lightning season in 1913, there were a total of about 1600 transformers which had been altered in this manner.

The records obtained during 1913 demonstrated, first, that the removal of the terminal boards from transformers would eliminate about 60 per cent of the troubles due to lightning, and second, that the installation of lightning arresters on the same pole with each transformer made a very considerable further reduction in the amount of trouble from lightning, as compared with our previous practise of installing a few arresters on the line poles. (The experiments from which these results were obtained were described in further detail in a paper read by the author before the Pittsfield meeting of the A. I. E. E., May, 1914.)

As a result of the experiments with the terminal boards, it was decided that it was desirable to remove the terminal boards from all transformers which were returned to the storeroom for any reason, and orders to this effect were issued early in 1914. At about the same time it was specified that all new transformers should be without terminal boards. During the period that has elapsed since these changes in our practise were adopted, the number of transformers from which the terminal boards were removed has approximately equaled the new transformers installed on our lines, each figure being about 10 per cent per year.

VII—Ratio between Fuses Blown and Transformers Burned Out

In the investigation of the storms that occurred in 1912, it was noted that a fairly constant ratio existed between the number

of blown primary fuses and the transformers burned out by lightning. As the number of burnouts by lightning per year was approximately 125, and as the number of transformers in the 100 per cent areas was only a small fraction of the total, it was thought that more accurate data and a better comparison of the several types of arresters could be secured by using the larger number. It was, therefore, arranged to keep careful records of all primary fuses blown, as well as of the transformer burnouts. These records and the ratio of the two quantities over a period of four years is shown in Fig. 3. From this figure it is very apparent that, while the ratio may perhaps be fairly constant during one lightning season, it has decreased very considerably during the four years. It is therefore quite impossible to use the record of blown primary fuses instead of the record of burned out transformers, in the manner described, for the purpose of comparing one year's records with another. The meaning of the reduction in the ratio will be discussed in connection with the results obtained during 1915.

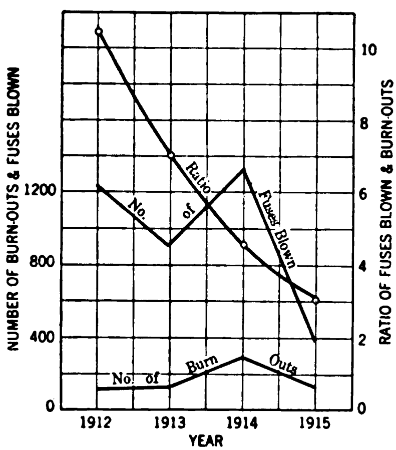


FIG. 3—RECORD FOR SEVERAL YEARS OF PRIMARY FUSES BLOWN AND TRANSFORMERS BURNED OUT BY LIGHTNING AND THEIR RATIO

VIII—GROUNDING OF TRANSFORMER CASES

The theory was also advanced that the grounding of the transformer cases would improve the lightning protection. In order to test this theory, three circuits on which there were about 600 transformers were selected, and each of the transformer cases was connected to the lightning arrester ground wire through a primary cut-out. This cut-out, with a piece of copper wire in place of the fuse, was located so that a lineman climbing the pole could readily remove the plug from the cut-out, and in this manner remove any hazard which might exist due to the grounded transformer case. Careful records were kept of this installation for a number of years. While it is entirely possible that the number of transformers included in the experiment

was inadequate for the purpose, and the records misleading due to the variableness of lightning storms, the results for three years appear to indicate that the grounding of the transformer cases has but little effect upon the efficiency of the lightning protection. As a matter of fact, there was slightly more trouble on these particular circuits than the average for other circuits, this trouble taking the nature of the burning off of the primary leads at or near the primary bushings. The area which was selected for this trial happened to be one of the older districts containing transformers which were considerably above the average age of all on the system. It is possible that the results would have been different with a modern type of transformer supplied with a larger primary bushing.

For the reasons above given, the scheme of grounding the transformer cases has been abandoned, and the ground connections installed for this purpose have been removed.

IX—Increasing the Size of Transformer Primary Fuses

Previous to the time of starting these experiments, it had been assumed that one of the principal objects of the primary fuse was to protect the transformers from over load, and the sizes of the fuses were proportioned to the capacity of the transformer. It was noted, however, that many fuses blew for which no cause could be found, and it was apparent that many fuses were blowing unnecessarily. After some discussion the old theory was abandoned, and instead a new theory was adopted, that the object of the primary fuse was to protect the service by disconnecting a defective transformer. As there were only two types of cut-outs in use, 25, ampere fuses were determined upon for use in the smaller cut-out for all transformers up to and including 10 kw., and 40-ampere fuses in the larger cut-out for transformers from 15 to 40 kw. capacity. Larger transformers are generally connected to the line without cut-outs. This rule, adopted in March 1914, was made to apply to all transformers installed, or to any fuses replaced for any reason after that date. This change in practise has resulted in a large reduction in the number of transformer fuses blown by other causes than lightning, but it is not clear that this change would have any serious effect on the blowing of fuses due to lightning, as this would mean that an arc started by the lightning would blow a five ampere fuse, for example, but that the arc might go out automatically without blowing a 25-ampere fuse. The facts

in the case are set forth, however, as it is possible that other engineers will not be entirely in accord with the author on this point.

X—Changes Made in 1914

As a result of the experiments with arresters on transformer poles, plans were adopted early in 1914, calling for some considerable additions to the 100 per cent areas for each of the several types of arresters. On account of the conditions existing at that time and the pressure of new construction work, the lightning arrester changes and additional installations were only partially completed before the opening of the lightning season. As further disturbances occurred during the middle of the summer the plans as adopted were not completely carried out until after the end of the year.

XI—Conclusions from the Records Obtained in 1914

As the changes planned for the year were only partially completed at the opening of the lightning season, and were not entirely completed until after the end of the year, the conditions were quite unfavorable for the securing of any accurate records. Although the results obtained during this year added very little to our knowledge regarding the best type of arresters, the records continued to indicate a very decided advantage for the scheme which is termed 100 per cent protection; and it further appeared that comparatively little benefit was being received from the lightning arresters installed on the line poles. As a result of this information, it was decided early in 1915 to increase the 100 per cent protection areas, (1) by moving all arresters on line poles, about 1000 in number, to the transformer poles, and (2) by installing about 3000 additional arresters. The 100 per cent areas completed previous to this time formed a broad ban across the city on the south side, in addition to a few small isolated areas on the north side. In planning the work for 1915, it was, therefore, arranged to extend the 100 per cent areas on the north side in such a manner that they would form a second band across this side of the city, and located so that it would include the most important customers. The increase year by year in the 100 per cent areas is shown in Fig. 4.

XII—Segregation of Lightning Arresters by Definite Boundaries

During the several years in which the scheme of segregating arresters by circuits had been followed, the number of primary

circuits had been increasing about 25 per cent per year. As new circuits were installed to handle the increase in load, it was necessary to move a considerable number of arresters each year in order to have only one type of arrester on each circuit. The plan was, therefore, changed so as to use streets, generally section lines, for the boundaries of the various lightning arrester districts. This change not only eliminated the annual expense

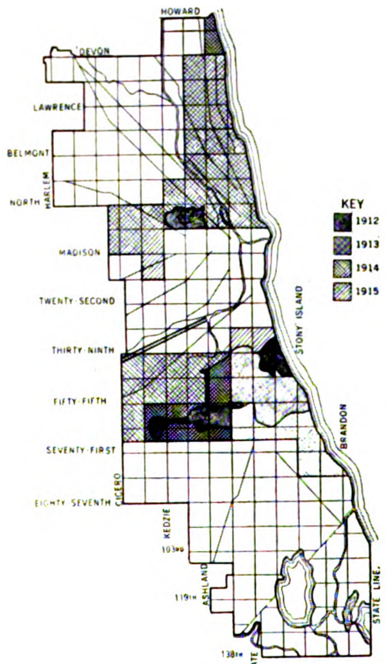


FIG. 4—MAP SHOWING 100 PER CENT AREAS FOR EACH YEAR 1912-1915

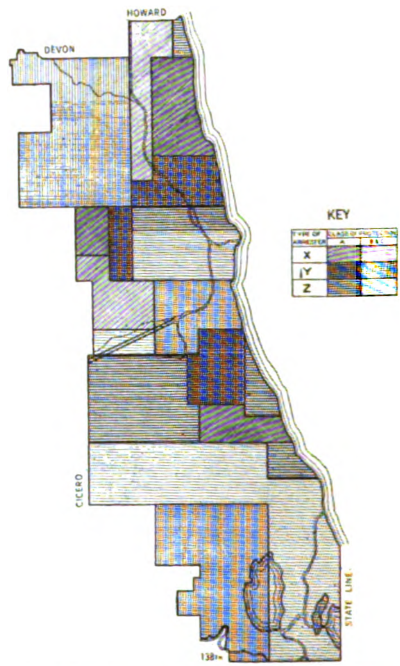


FIG. 5—MAP SHOWING SUB-DIVISION OF CITY BY TYPE OF ARRESTER AND CLASS OF PROTECTION DURING 1915

of moving arresters, which was continually increasing, but it also greatly simplified the keeping of the records and their subsequent analysis.

XIII—INSTALLATION OF ARRESTERS ON TRANSFORMER POLES OUTSIDE THE 100 PER CENT AREAS

As the results of the experience obtained in 1912 indicated that a considerable improvement in the service could be secured by

the installation of arresters on the transfomer poles, it was decided that the extra expense of such installations was warranted in the case of important customers. Beginning in February, 1913, the plan was therefore adopted, of installing a lightning arrester on the same pole with each transformer of 15 kw. capacity or larger. In March, 1914, this rule was altered so as to include all transformers of 7.5 kw. and larger, which were thereafter installed, changed or moved. A few weeks later the rule was extended so as to include all transformers for supplying power customers, regardless of their size. In April, 1915, the rule was again altered so as to include all transformers above 3 kw. capacity.

XIV—Conditions at the Beginning of 1915

At the opening of the lightning season in 1915 there were in service three classes of protection, designated hereinafter as classes A, B and C and described as follows:

Class A. This includes the transformers which have an arrester on the same pole, and which are located in the so-called 100 per cent areas, that is, in areas in which each transformer is similiarly protected.

Class B. This includes the transformers outside of the 100 per cent areas, which are protected by arresters on the same pole as the result of the rules adopted from time to time and set forth under heading XIII.

Class C. This includes all transformers that are not protected by arresters on the same pole, and together with the class B includes all transformers outside the 100 per cent areas.

All transformers included in this investigation come under one of the three above described classes. There are no lightning arresters installed on line poles for the protection of transformers, except in a very few isolated cases where the equipment of other companies on jointly owned transformer poles interfered with the installation of the arrester on such poles.

The manner in which the several types of arresters were distributed throughout the city is shown in Fig. 5. The letters *X*, *Y* and *Z* used on this map serve to designate the several types of arresters, and these letters are used throughout the various tables and discussions. The heavy shading on this map indicates the 100 per cent protection areas, and for convenience in making comparisons, the boundaries of these areas have been shown by heavy lines on other similar maps. Each of the several areas

TABLE I.

DATA ON THE SIZES OF THE TRANSFORMERS IN THE SEVERAL DISTRICTS

Area No.	Type of arrester	Class of protection	Sq. mile	No. of transformers: Below 5 kv-a.	5 to 15 kv-a	Above 15 kv-a.	Total	Transformer per sq. mile
3	X	A	7.8	327	779	193	1299	167
8	..	..	3.0	126	138	16	280	93
16	..	..	4.0	228	314	138	710	178
..	..	.	14.8	681	1261	347	2289	155
5	Y	A	6.5	392	759	160	1311	202
7	..	..	3.0	160	280	52	492	164
13	..	..	7.0	313	489	173	975	139
			16.5	865	1528	385	277[illegible]	168
6	Z	A	4.3	132	378	80	590	137
14	..	..	9.0	281	178	47	506	56
15	..	..	3.0	100	185	129	414	138
18	..	..	2.0	127	64	3	194	97
1	..	..	0.8	38	73	6	117	130
17	..	..	7.5	420	259	35	714	95
..	..	..	26.6	1098	1137	300	2535	95
TOTAL	ALL	A	57.9	2644	3926	1032	7602	131
2	X	B	7.0	13	29	18	60	9
10	..	..	7.5	13	97	88	198	26
..	..	..	14.5	26	126	106	258	18
4	Y	B	28.5	28	67	41	136	5
11	..	..	9.2	69	180	109	358	39
20	..	..	19.5	35	54	37	126	7
21	..	..	2.0	1	3	1	5	3
..	..	..	59.2	133	304	188	625	11
9	Z	B	9.2	51	209	115	405	45
12	..	..	3.0	11	6	14	31	10
19	..	.	36.5	139	186	61	386	11
..	..	..	48.7	201	401	220	822	17
TOTAL	ALL	B	122.4	360	831	514	1705	14
2	X	C	7.0	221	129	44	394	56
10	..	..	7.5	378	392	54	824	110
..	.	..	14.5	599	521	98	1218	84
4	Y	C	28.5	926	542	36	1504	53
11	..	..	9.2	355	362	49	746	81
20	..	..	19.5	429	146	11	586	30
21	..	..	2.0	35	7	6	48	24
..	..	..	59.2	1725	1057	102	2884	49
9	Z	C	9.2	310	643	93	1076	117
12	..	..	3.0	37	23	6	66	33
19	.	..	36.5	712	300	12	1054	29
..	.	..	48.7	1119	966	111	2196	45
TOTAL	ALL	C	122.4	3143	2544	311	6298	51
GRAND TOTALS		ALL	180.3	6417	7301	1857	15,605	85

was given a number and these numbers are used consistently throughout the records, but in order to avoid confusion, have been omitted from the map.

In order to assist in analyzing the results, the transformers were divided into three classes according to their size, and the number of each of the three classes in each of the areas is given in Table I. For the simplification of the calculations, the number of transformers in service on August 1st, 1915, which was approximately the middle of the lightning season, was taken as the basis of this table. From this information the percentage distribution of the transformers in the territories corresponding to each type of arrester and class of protection is shown in Table II.

TABLE II.

SUMMARY OF LIGHTNING ARRESTER DISTRICTS, SHOWING THE PERCENTAGE DISTRIBUTION OF THE TRANSFORMERS AMONG THE DISTRICTS BY GROUPS OF SIZES.

Class of protection	Type of arrester	Distribution per cent.			
		Below 5 kv-a.	5 to 15 kv-a.	Above 15 kv-a.	Total
A	X	30	15	55	100
..	Y	31	55	14	100
..	Z	43	45	12	100
..	ALL	35	51	14	100
B	X	10	49	41	100
..	Y	21	49	30	100
..	Z	24	49	27	100
..	ALL	21	49	30	100
C	X	49	43	8	100
..	Y	60	37	3	100
..	Z	51	44	5	100
	ALL	55	40	5	100
A B C	X	35	50	15	100
..	Y	43	46	11	100
..	Z	43	45	12	100
..	ALL	41	47	12	100

XV—Records Obtained in 1915

A list of all the transformers burned out by lightning during the year with the size, area number, type of arrester and class of protection for each transformer is given in Table III.

TABLE III.
CLASSIFIED LIST OF TRANSFORMERS BURNED OUT BY LIGHTNING IN 1915.

Type of arrester				X			Y			Z			Nature of burnout
Class of protection				A	B	C	A	B	C	A	B	C	
No. of storm	Date	Size of trans-former kw.	Area No.										
1	May 3	10	9									×	Damaged
2	15	7½	2		×								Coils
		1½	2			×							"
		7½	4			×							"
		1½	4			×							"
		1	6							×			Damaged
		3	6							×			"
		7½	9									×	"
		2	9									×	"
		4	10			×							Coils
		3	10			×							"
		2	10			×							Damaged
		10	11						×				"
		1½	12									×	"
		3	14							×			Coils
		3	14							×			Damaged
		5	14							×			Coils
		15	15							×			"
		3	17							×			"
		5	17							×			Damaged
		5	17							×			Coils
		4	19								×		"
		5	20						×				Damaged
		10	20						×				"
		1½	20						×				Coils
3	June 7	10	9									×	"
		7½	6							×			Damaged
4	11	5	11						×				"
		5	9								×		Coils
5	12	4	4						×				Damaged
		1½	4						×				"
		1½	4						×				"
		1½	4						×				"
		4	4						×				Coils
		3	4						×				"
		1½	4						×				Damaged
		7½	4						×				"
		50	11						×				"
		2	11						×				"
		3	18							×			Coils
		2	19									×	"
		1½	19									×	"
		5	20						×				"
6	July 10	1½	19									×	Damaged
		5	19									×	"
Carried Forward				0	1	6	0	0	16	11	2	9	45

TABLE III. (*Continued*)
CLASSIFIED LIST OF TRANSFORMERS BURNED OUT BY LIGHTNING IN 1915.

Type of arrester				X			Y			Z			Nature of burnout
Class of protection				A	B	C	A	B	C	A	B	C	
No. of storm	Date	Size of transformer kw.	Area No.										
Brought Forward				0	1	6	0	0	16	11	2	9	45
7	July 11	1½	19	..	..	..	..	..	..	..	..	×	Coils
		2	11	..	..	..	..	..	×	..	..	..	"
8	12	3	17	..	..	..	..	..	..	×	..	..	"
9	14	7½	13	..	..	..	×	..	..	..	..	..	Damaged
		1½	19	..	..	..	..	..	..	..	..	×	Coils
		10	16	×	..	..	..	..	..	..	..	..	Damaged
10	15	5	19	..	..	..	..	..	..	..	..	×	Coils
11	18	3	10	..	..	×	..	..	..	..	..	..	"
		7½	9	..	..	..	..	..	..	..	..	×	"
		15	9	..	..	..	..	..	..	..	×	..	"
12	Aug. 14	20	3	×	..	..	..	..	..	..	..	..	Damaged
		1½	5	..	..	..	×	..	..	..	..	..	Coils
		4	4	..	..	..	..	..	×	..	..	..	"
		7½	4	..	..	..	..	..	×	..	..	..	Damaged
		2	4	..	..	..	..	..	×	..	..	..	"
		1½	4	..	..	..	..	..	×	..	..	..	"
		1½	4	..	..	..	..	..	×	..	..	..	Coils
		1	20	..	..	..	..	..	×	..	..	..	"
		2	20	..	..	..	..	..	×	..	..	..	"
13	Aug. 16	2	17	..	..	..	..	..	..	×	..	..	"
		3	19	..	..	..	..	..	..	..	..	×	"
		7½	19	..	..	..	..	..	..	..	..	×	Damaged
		4	19	..	..	..	..	..	..	..	..	×	"
		3	19	..	..	..	..	..	..	..	..	×	"
		1½	19	..	..	..	..	..	..	..	..	×	Coils
		1	19	..	..	..	..	..	..	..	..	×	Damaged
		5	19	..	..	..	..	..	..	..	..	×	"
		3	19	..	..	..	..	..	..	..	..	×	Coils
		2	19	..	..	..	..	..	..	..	..	×	Damaged
		1	19	..	..	..	..	..	..	..	..	×	Coils
		10	19	..	..	..	..	..	..	..	..	×	Damaged
		5	20	..	..	..	..	..	×	..	..	..	Coils
		2	20	..	..	..	..	..	×	..	..	..	"
		2	20	..	..	..	..	..	×	..	..	..	Damaged
		1	20	..	..	..	..	..	×	..	..	..	"
		7½	20	..	..	..	..	..	×	..	..	..	Coils
		5	20	..	..	..	..	..	×	..	..	..	"
		1½	20	..	..	..	..	..	×	..	..	..	Damaged
		2	20	..	..	..	..	..	×	..	..	..	Coils
		2	20	..	..	..	..	..	×	..	..	..	Damaged
		2	20	..	..	..	..	..	×	..	..	..	Coils
		4	20	..	..	..	..	..	×	..	..	..	"
		1½	20	..	..	..	..	..	×	..	..	..	Damaged
		2	20	..	..	..	..	..	×	..	..	..	Coils
		3	20	..	..	..	..	..	×	..	..	..	"
Carried Forward				2	1	7	2	0	38	13	3	24	90

TABLE III. (*Continued*)
CLASSIFIED LIST OF TRANSFORMERS BURNED OUT BY LIGHTNING IN 1915.

Type of arrester				X			Y			Z			Nature of burnout
Class of protection				A	B	C	A	B	C	A	B	C	
No. of storm	Date	Size of transformer kw.	Area No.										
Brought Forward				2	1	7	2	0	38	13	3	24	90
13	Aug. 16	1	20	..	..	..	..	..	×	..	..	..	Coils
		3	20	..	..	..	..	..	×	..	..	..	"
		7½	20	..	..	..	..	..	×	..	..	..	Damaged
		1½	20	..	..	..	..	..	×	..	..	..	"
		3	20	..	..	..	..	..	×	..	..	..	Coils
		2	20	..	..	..	..	..	×	..	..	..	"
		1½	20	..	..	..	..	..	×	..	..	..	"
		3	20	..	..	..	..	..	×	..	..	..	"
		3	20	..	..	..	..	..	×	..	..	..	"
		3	20	..	..	..	..	..	×	..	..	..	"
		4	20	..	..	..	..	..	×	..	..	..	Damaged
		7½	21	..	..	..	..	..	×	..	..	..	Coils
		2	21	..	..	..	..	..	×	..	..	..	"
14	Aug. 23	3	13	..	..	..	..	..	×	..	..	..	"
		7½	11	..	..	..	..	..	×	..	..	..	"
15	Sep. 8	1½	4	..	..	..	..	..	×		..	..	Damaged
		3	4	..	..	..	..	..	×	..	..	..	Coils
		2	4	..	..	..	..	..	×	..	..	..	"
		3	4	..	..	..	..	..	×	..	..	..	Damaged
		3	4	..	..	..	..	..	×	.	..	..	Coils
		1½	4	..	..	.	..	..	×	..	..	..	"
		7½	5	..	..	..	×	..	..	..	..	..	"
		2	9	..	..	..	..	..	..	..	..	×	"
		1½	10	..	..	×	..	..	..	..	..	..	"
		5	14	..	..	..	..	..	..	..	..	×	Damaged
		3	19	..	..	..	..	..	..	..	×	..	Coils
		2	19	..	..	..	..	..	..	..	..	×	"
		3	19	..	..	..	..	..	..	..	..	×	"
		2	19	..	..	..	..	..	..	..	..	×	"
16	Sep. 10	20	7	..	..	..	..	..	×	..	..	..	Damaged
		3	18	..	..	..	..	..	..	×	..	..	Coils
		5	18	..	..	..	..	..	..	×	..	..	"
		1	19	..	..	..	..	..	..	..	..	×	Damaged
GRAND TOTAL				2	1	8	3	0	60	15	4	30	73 Coils 50 Damage

" Damaged " means transformer disabled by damage to leads or otherwise without injuring coils.

The location of all the transformers burned out by lightning in 1915 is shown in Fig. 6, and the fuses blown by lightning are shown in a similar way in Fig. 7. By comparing these maps with Fig. 2 it will be noted that in the 100 per cent areas where the transformers are most numerous, the burnouts and fuses blown were quite scattering, while outside of the 100 per cent areas, in which regions the transformers are not so numerous

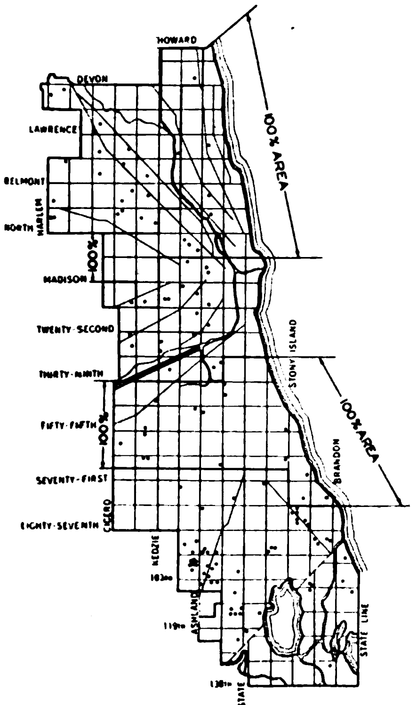


FIG. 6—TRANSFORMER BURN-OUTS DUE TO LIGHTNING 1915. EACH DOT REPRESENTS ONE BURN-OUT

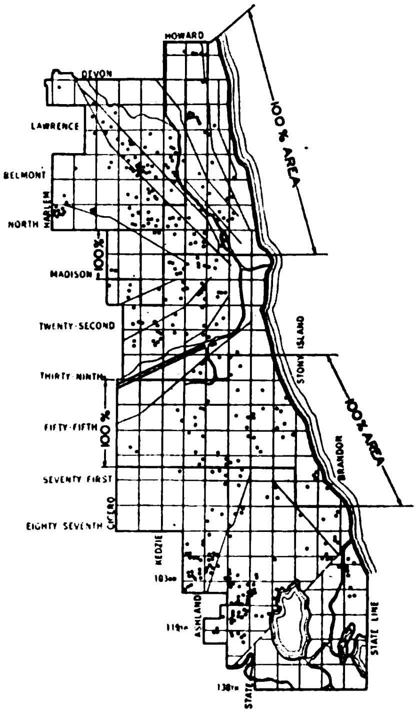
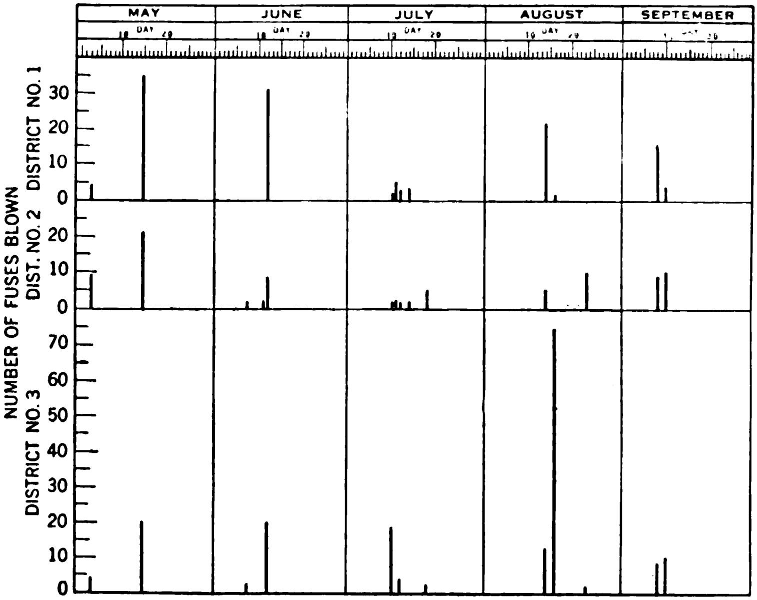


FIG. 7—FUSES BLOWN BY LIGHTNING 1915. EACH DOT REPRESENTS ONE BLOWN PRIMARY FUSE

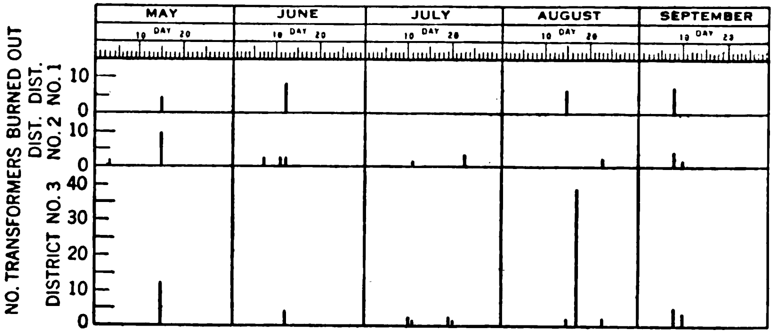
that the burn-outs and fuses blown are more numerous, thus indicating a distinct reduction in the percentage of burn-outs and fuses blown within the 100 per cent areas.

Fig. 8 is a diagram showing the number of fuses blown and transformers burned out by lightning during the year, the arrangement being by districts. The boundaries of the districts are North Avenue and 39th Street, extending across the city from east to west. The districts are numbered in order, District

No. 1 being at the north and No. 3 at the south end of the city. This diagram shows how the various lightning storms were distributed throughout the season and among the various sections of the city. From this diagram the impression is obtained that



FUSES BLOWN IN LIGHTNING STORMS - 1915.



TRANSFORMERS BURNED OUT BY LIGHTNING - 1915.

FIG. 8

the storms of May 15th and August 16th were somewhat more erratic than the other storms and for the purpose of elucidating this point, the effects of these two storms are shown graphically in Figs. 9 and 10.

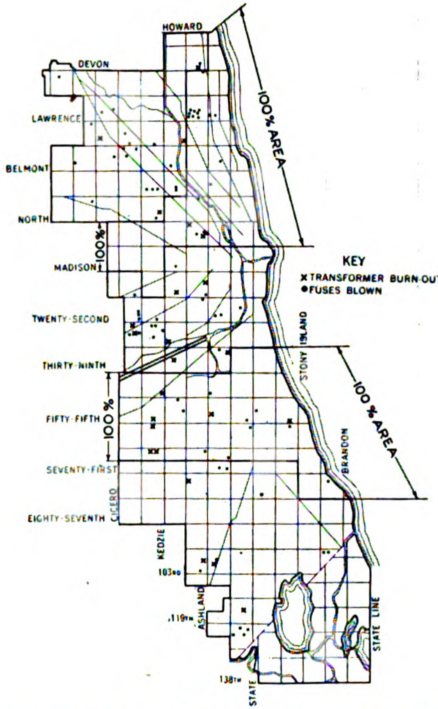


FIG. 9—TRANSFORMER BURN-OUTS AND FUSES BLOWN BY LIGHTNING STORM MAY 15, 1915

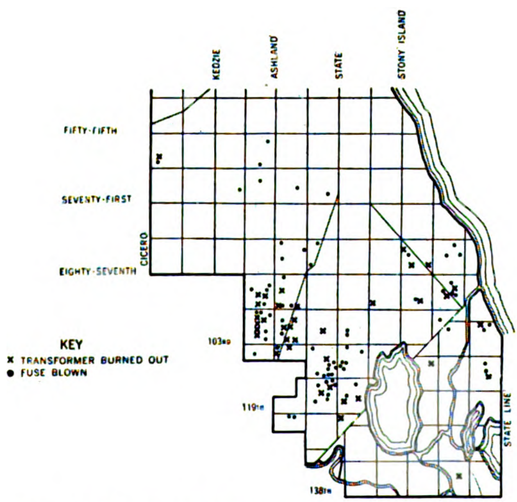


FIG. 10—LIGHTNING STORM OF AUG. 16, 1915

TABLE IV
RECORD OF TROUBLES DUE TO LIGHTNING STORMS DURING 1915.
ARRANGED BY AREAS.

Area No.	Type of arrester	Class of protection	Transformers in area	Transformers burned out		Primary fuses blown only	
				No.	Per cent	No.	Per cent
3	X	A	1299	1	0.077	17	1.31
8	..	..	280	0	0	3	1.07
16	..	..	710	1	0.141	6	0.84
..	..	..	2289	2	0.087	26	1.13
5	Y	A	1311	2	0.015	19	1.45
7	..	..	492	0	0.	5	1.02
13	..	..	975	1	0.102	11	1.13
..	..	..	2778	3	0.108	35	1.26
6	Z	A	590	3	0.51	8	1.35
14	..	..	506	3	0.59	7	1.38
15	..	..	414	1	0.24	7	1.69
18	..	..	194	3	1.54	5	2.58
1	..	..	117	0	0	0	0
17	..	..	714	5	0.70	9	1.26
..	..	..	2535	15	0.56	36	1.42
TOTAL	ALL	A	7602	20	0.26	97	1.27
2	X	B	60	1	1.67	0	0
10	..	..	198	0	0	2	1.01
..	..	..	258	1	0.39	2	0.77
4	Y	B	136	0	0	1	0.73
11	..	..	358	0	0	2	0.56
20	..	..	126	0	0	0	0
21	..	..	5	0	0	0	0
..	..	..	625	0	0	3	0.48
9	Z	B	405	2	0.49	4	0.98
12	..	..	31	0	0	0	0
19	..	..	386	2	0.52	5	1.29
..	..	..	822	4	0.49	9	1.09
TOTAL	ALL	B	1705	5	0.29	14	0.82
2	X	C	394	1	0.25	16	4.06
10	..	..	824	5	0.61	19	2.31
..	..	..	1218	6	0.49	35	2.88
4	Y	C	1504	21	1.40	72	4.78
11	..	..	746	8	1.07	16	2.14
20	..	..	586	31	5.29	88	15.01
21	..	..	48	2	4.16	0	0
..	..	..	2884	62	2.14	176	6.10
9	Z	C	1076	6	0.56	25	2.32
12	..	..	66	2	3.03	0	0
19	..	..	1054	22	2.08	35	3.32
			2196	30	1.36	60	2.73
TOTAL	ALL	C	6298	98	1.56	271	4.30
GRAND TOTALS			15,605	123	.79	382	2.44

Table IV gives a record, by areas, of the transformer trouble due to lightning, segregated by the type of arrester and class of protection. For the purpose of a better comparison the percentage figure of transformer troubles for the various classes of protection and types of arresters have been collected in Table V. Table VA shows the nature of damage to the transformers for each type of arrester and class of protection.

Tables VI and VII give a classified record, arranged by storms, of transformers burned out and primary fuses blown respectively during the year. From these tables, Figs. 11 and 12 have

TABLE V.

SUMMARY OF LIGHTNING TROUBLES DURING 1915, SHOWING THE RESULTS FOR EACH TYPE OF ARRESTER AND CLASS OF PROTECTION.

Class of protection	Type of arrester	Burn-outs per cent	Fuses blown per cent
A	X	0.087	1.13
..	Y	0.108	1.26
..	Z	0.59	1.42
	ALL	0.26	1.27
B	X	0.39	0.77
..	Y	0	0.48
..	Z	0.49	1.09
..	ALL	0.29	0.82
C	X	0.49	2.85
..	Y	2.14	6.10
..	Z	1.36	2.73
	ALL	1.56	4.30

been prepared, showing graphically the variations during the season of the percentage of transformers burned out and fuses blown. These tables and the figures also show plainly the erratic nature of the storms of May 15th and August 16th. It will be noted, for example, that 60 per cent of the total number of burn-outs for type *Z* arrester and class A protection occurred on May 15th, although the total number of transformers burned out on this day was only 20 per cent of the total occurring dur- the season.

Table VIII gives data regarding the transformer troubles for each size of transformer. These troubles have been further

TABLE NO. 5-A

TRANSFORMERS BURNED OUT BY LIGHTNING DURING 1915 CLASSIFIED BY TYPE OF PROTECTION AND EXTENT OF DAMAGE.

	No. of burn-outs							
Class of protection	A and B				C			All
Type of arrester	X	Y	Z	Total	X	Y	Z	Total
Coils burned out..........	1	3	16	20	5	40	20	65
Transformers put out of commission, but coils O.K.	2	0	3	5	1	22	10	33
Totals...............	3	3	19	25	6	62	30	98

TABLE VI.

RECORD OF TRANSFORMERS BURNED OUT BY LIGHTNING IN 1915, ARRANGED BY STORMS.

Type of arrester		X			Y			Z			TOTALS			Grand Total
Class of protection		A	B	C	A	B	C	A	B	C	A	B	C	
No. of storm	Date													
1	May 3	0	0	0	0	0	0	0	0	1	0	0	1	1
2	15*	0	1	6	0	0	4	9	1	3	9	2	13	24
3	June 7	0	0	0	0	0	0	1	0	1	1	0	1	2
4	11	0	0	0	0	0	1	0	1	0	0	1	1	2
5	12	0	0	0	0	0	11	1	0	2	1	0	13	14
6	July 10	0	0	0	0	0	0	0	0	2	0	0	2	2
7	11	0	0	0	0	0	1	0	0	1	0	0	2	2
8	12	0	0	0	0	0	0	1	0	0	1	0	0	1
9	14	1	0	0	1	0	0	0	0	1	2	0	1	3
10	15	0	0	0	0	0	0	0	0	1	0	0	1	1
11	18	0	0	1	0	0	0	0	1	1	0	1	2	3
12	Aug. 14	1	0	0	1	0	7	0	0	0	2	0	7	9
13	16	0	0	0	0	0	27	1	0	11	1	0	38	39
14	23	0	0	0	0	0	2	0	0	0	0	0	2	2
15	Sep. 8	0	0	1	1	0	6	0	1	5	1	1	12	14
16	10	0	0	0	0	0	1	2	0	1	2	0	2	4
	TOTALS	2	1	8	3	0	60	15	4	30	20	5	98	123

*The two storms occurring on May 15th, one in the early morning and one in the late afternoon, have been classed as one storm, on account of the impossibility of making an accurate separation.

segregated in Tables IX and X so as to show the variation in the percentage of trouble in the transformers supplied by various manufacturers. The percentage figures from Table VIII have been plotted in Fig. 13, and there has been added, for the purpose of comparison, the corresponding information from the records of 1913.

TABLE VII.

RECORD OF TRANSFORMER PRIMARY FUSES BLOWN BY LIGHTNING IN 1915, ARRANGED BY STORMS.

Type of arrester		X			Y			Z			Totals			Grand Total
Class of protection		A	B	C	A	B	C	A	B	C	A	B	C	
No. of storm	Date													
1	May 3	2	0	1	3	0	4	1	0	7	6	0	12	18
2	15*	11	0	14	5	0	30	8	1	8	24	1	52	77
3	June 7	0	0	0	0	0	0	1	1	0	1	1	0	2
4	11	1	0	0	0	0	0	0	0	0	1	0	0	1
5	12	3	0	9	8	1	26	10	0	3	21	1	38	60
6	July 10	3	0	0	0	0	16	0	0	1	3	0	17	20
7	11	0	0	1	1	0	3	0	0	2	1	0	6	7
8	12	0	0	0	0	0	7	0	0	1	0	0	8	8
9	14	0	0	1	3	0	0	0	0	0	3	0	1	4
10	15	0	0	0	0	0	0	0	0	0	0	0	0	0
11	18	0	0	1	2	0	0	0	0	3	2	0	4	6
12	Aug. 14	4	0	3	4	1	26	1	0	0	9	1	29	39
13	16	0	0	0	1	0	42	4	2	26	5	2	68	75
14	23	0	1	2	0	0	4	1	0	2	1	1	8	10
15	Sep. 8	2	0	2	3	0	14	3	3	4	8	3	20	31
16	10	0	1	1	5	1	4	7	2	3	12	4	8	24
	Totals	26	2	35	35	3	176	27	9	60	97	14	271	382

*The two storms occurring on May 15th, one in the early morning and one in the late afternoon, have been classed as one storm, on account of the impossibility of making an accurate separation.

Fig. 14 shows the ratio of primary fuses blown to transformer burn-outs during the year for each class of protection. The variations in the ratio for all classes of protection are shown in Fig. 15 to which has also been added, for comparison, similar information for 1913.

XVI—Comments on the Analysis of the Records

In attempting to analyze the records and to discover the fundamental principles of lightning protection, not only is one con-

fronted by records which are incomplete and inaccurate due to the errors which naturally creep into any records that are collected from so many sources, and through so many individuals but there are a large number of variables affecting the amount of trouble due to lightning, which might be roughly outlined as follows:

1. The percentage of terminal boards removed.
2. The ratio of lightning arresters to transformers.

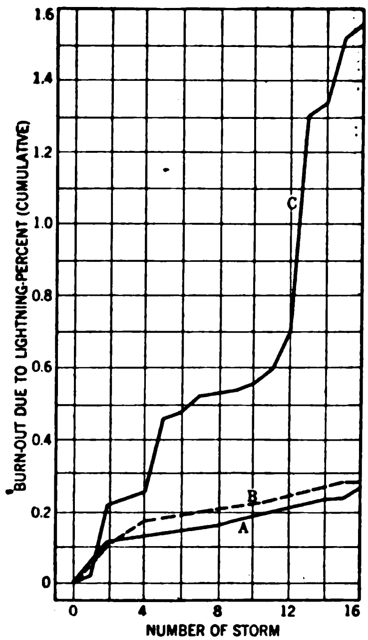


FIG. 11—GRAPHIC LOG OF TRANSFORMERS BURNED OUT BY LIGHTNING IN 1915, SUBDIVIDED BY CLASSES OF PROTECTION

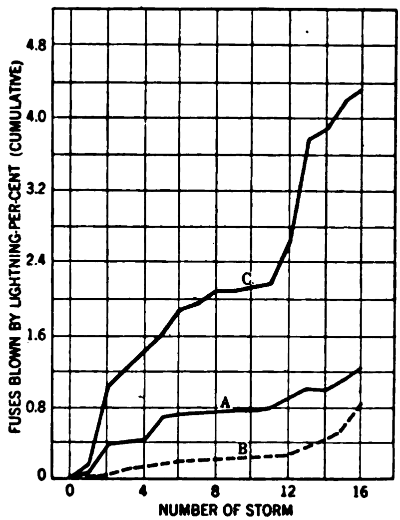


FIG. 12—GRAPHIC LOG OF FUSES BLOWN BY LIGHTNING IN 1915, SUB-DIVIDED BY CLASSES OF PROTECTION

3. Location of the lightning arresters, *i.e.*, whether on the line poles or transformer poles.
4. Density of the arresters, *i.e.*, the number per square mile or per mile of line.
5. The maker of the transformer.
6. The variations in the distribution and intensity of the lightning.

In general the variations of the lightning itself overshadow the rest of the variables so that the latter are sometimes quite insigni-

ficant in comparison. In other cases the variations in the variables apparently oppose each other, or perhaps act together in such a way that their effect becomes very obscure.

The large variations due to the lightning itself, may be noted in any of the records which give percentage figures for the various numbered areas, and from these records we gather that it is quite unsafe to assume that the record for any particular area correctly represents the average conditions throughout the city. The most representative figures are those which are obtained

TABLE VIII.

RECORD OF TRANSFORMER TROUBLES CAUSED BY LIGHTNING IN 1915, FOR EACH SIZE OF TRANSFORMER

Size kw.	Transformers in service August 1st, 1915.	Burned out		Fuses blown	
		No.	Per cent	No.	Per cent
1	407	7	1.72	22	5.41
1.5	1,090	23	2.11	61	5.59
2	1,103	21	1.90	51	4.61
3	2,381	25	1.05	51	2.14
4	1,149	8	0.70	20	1.74
5	2,075	14	0.67	54	2.60
7.5	2,304	14	0.61	61	2.64
10	1,852	6	0.32	35	1.89
15	1,320	2	0.15	16	1.21
20	648	2	0.31	2	0.31
25	451	0	0	3	0.67
30	186	0	0	1	0.54
40	152	0	0	1	0.66
50	243	1	0.41	4	1.65
75	114	0	0	0	0
100	117	0	0	0	0
150	12	0	0	0	0
250	1	0	0	0	0
TOTALS	15,605	23	0.78	382	2.44

from the combined experience in a number of areas. In some cases this is not possible, and in those particular cases the attempt to plot the relation between any quantity and the effects of the lightning are quite dissappointing.

It is also to be noted that in attempting to find the relation between any one variable and the lightning effects, the other variables must for the moment be assumed as constant. The records show that this last assumption is always in error to a greater or less extent. Sometimes the variations from the assumption is not sufficient to seriously affect the records, but in other

TABLE IX.

TRANSFORMER BURNOUTS DUE TO LIGHTNING DURING 1915, FOR EACH SIZE AND MAKE OF TRANSFORMER PER CENT

Maker	A	B	C	D	E	Total
Size kw.						
1	0	1.55	....	....	16.65	1.72
1.5	1.43	1.17	1.40	0	10.48	2.11
2	1.11	1.73	2.61	0	7.41	1.90
3	0.29	0.96	0.97	0	6.06	1.05
4	0	0.65	1.00	6.67	....	0.70
5	0	0.83	0.46	0	0	0.67
7.5	1.04	0.39	0	0	2.20	0.61
10	0.45	0	1.74	0	0.84	0.32
15	0	0.13	0.72	0	0	0.15
20	1.89	0	0	16.65	0	0.31
25	0	0	0	....	0	0
30	0	0	0	0	0	0
40	0	0	0	0	0	0
50	0	0	0	9.09	0	0
TOTALS	0.51	0.66	0.81	1.47	1.69	0.78

TABLE X.

TRANSFORMER FUSES BLOWN BY LIGHTNING FOR EACH SIZE AND MAKE OF TRANSFORMER DURING 1915

Maker	A	B	C	D	E	Total
Size kw.						
1	12.5	5.5	....	0	0	5.41
1.5	5.7	5.8	4.9	....	4.8	5.59
2	4.5	4.4	7.8	0	0	4.61
3	1.4	2.2	3.5	0	1.0	2.14
4	1.8	1.7	2.0	0	....	1.74
5	3.3	2.3	3.2	0	7.5	2.60
7.5	2.1	2.3	5.6	4.0	2.6	2.64
10	2.3	1.5	4.4	5.0	1.7	1.89
15	1.6	1.3	2.9	0	0	1.21
20	1.9	0.3	0	0	0	0.31
25	0	0.8	0	....	0	0.67
30	0	1.2	0	0	0	0.54
40	0	1.1	0	0	0	0.66
50	0	2.5	0	0	0	1.65
TOTALS	2.34	1.33	3.55	1.47	1.33	2.44

NOTE: The letters used to represent the maker, correspond with those used in Table 9

cases the variations are apparently so great that it is quite impossible to draw any conclusions from the results obtained, except in a very general way.

XVII—Reduction in the Ratio of Primary Fuses Blown to Transformers Burned Out

While the number of primary fuses blown and the burnouts due to lightning during the past four years have varied over

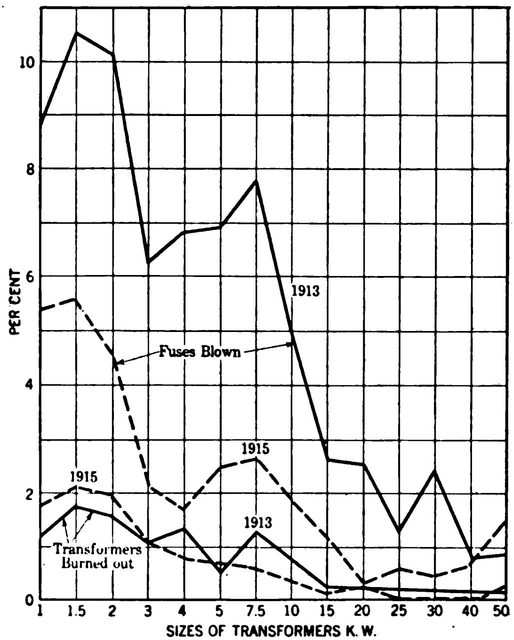


Fig. 13—Comparative Records of Primary Fuses Blown and Transformers Burned Out by Lightning in 1913 and 1915

rather wide limits from year to year as shown in Fig. 3, the ratio between these two quantities during the same period has been decreasing along a very regular curve, indicating the existence of some law or progressive change connecting these two quantities. For the purpose of securing information on this point, Table XI has been prepared showing the ratio in question for the several classes of protection during 1915. This table shows that the ratio is smaller for the class B and C protection than for class A. This ratio, being the larger for the best class

of protection, indicates that the other variables have a greater effect on this ratio than the lightning arresters.

Fig. 16, showing the reduction in the percentage of terminal boards and in the percentage of fuses blown by lightning, indicates that there must be some close relation between these two quantities as indicated by the fact that the curves are, in general parallel. (In this figure the values for transformers above 15 kw. capacity have been omitted, as not more than four fuses of

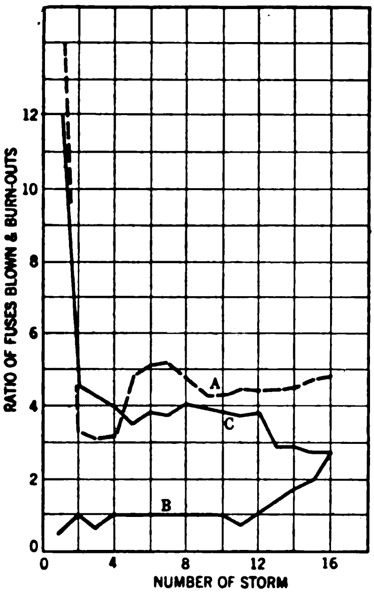


FIG. 14—DIAGRAM SHOWING RATIO OF FUSES BLOWN TO TRANSFORMERS BURNED OUT BY LIGHTNING IN 1915 FOR VARIOUS CLASSES OF PROTECTION

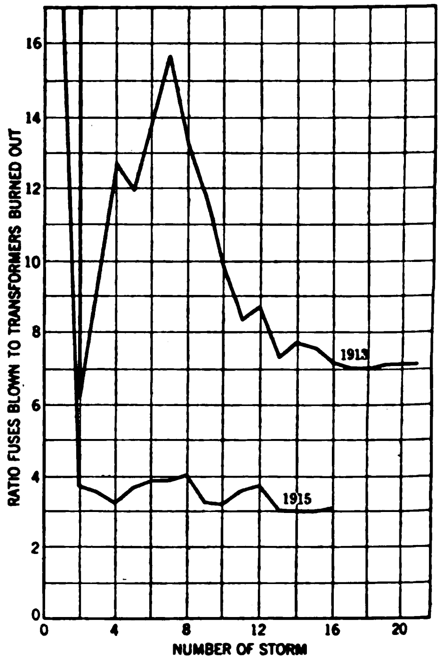


FIG. 15—DIAGRAM SHOWING RATIO OF PRIMARY FUSES BLOWN TO TRANSFORMERS BURNED OUT BY LIGHTNING IN 1913 AND 1915

any of these sizes were blown during the year.) In order to determine the relation between the removal of the terminal boards and the reduction in the fuses blown, these two quantities have been plotted directly in Fig. 17. After making due allowance for the various inaccuracies in the assumptions and conditions, the points from Fig. 16 when plotted in this manner show that the relation between the two quantities is a function represented by a straight line passing through the origin, or in other

words, that the percentage reduction in fuses blown is directly proportional to the percentage of terminal boards removed.

Upon examining this line more carefully, an apparent incon-

TABLE XI.

EFFECT OF CLASS OF PROTECTION ON RATIO OF FUSES BLOWN TO TRANSFORMERS BURNED OUT IN 1915.

Class of protection	A Primary fuses blown	B Transformers burned out	Ratio $\frac{A}{B}$
A	97	20	4.85
B	14	5	2.80
C	271	98	2.75

sistency is noted in that the removal of 30 per cent of the terminal boards caused a reduction of 59 per cent in the fuses blown by lightning. Such a result could occur only if some

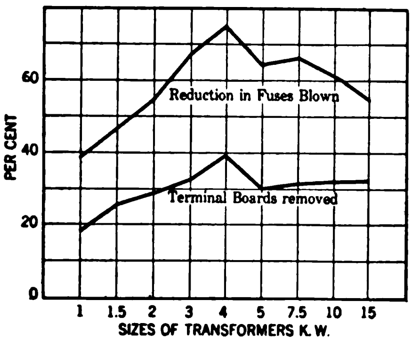


FIG. 16—DIAGRAM SHOWING EFFECT OF REMOVAL OF TERMINAL BOARDS FOR TWO YEARS ON PERCENTAGE OF FUSES BLOWN BY LIGHTNING

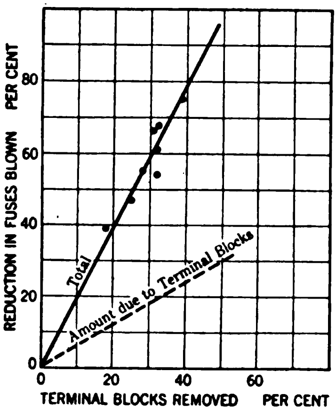


FIG. 17—DIAGRAM SHOWING RELATION BETWEEN REMOVAL OF TERMINAL BOARDS AND REDUCTION IN BLOWING OF PRIMARY FUSES

scheme of selection were practised in the removal of the primary terminal boards, so that the ones most likely to cause trouble were the ones to be removed; but no such scheme of selection has been in use, and instead, all of the transformers passing

through the storeroom have had their terminal boards removed before again being sent out on the line.

In the paper by the author read at Pittsfield in 1914, and previously referred to, it was stated that the removal of all of the terminal boards from the transformers in a given area eliminated about 60 per cent of the transformer troubles caused by lightning. Assuming for the moment that this figure is correct, then we might reasonably conclude that the removal of 30 per cent of the terminal boards should reduce the troubles by 30 per cent of 60 per cent, or 18 per cent. The dash line in Fig. 17 shows this value. If we assume that this line is correctly drawn, then the percentage reduction in fuses blown between the dash line and the full line must be due to other causes.

During the same period, that is, between 1913 and 1915, the lightning protection of the system has been improved, (1) by increasing the number of arresters on the line, and (2) by moving the arresters from the line poles to the transformer poles. It is not thought that any of the other changes made during this period could have seriously affected the ratio. The difference between the dash line and the full line on Fig. 17, apparently, must be ascribed to the improvement in the lightning protection secured by the lightning arresters. The records available do not permit of an exact determination of the benefits derived from increasing the number of arresters as distinguished from the benefits obtained by moving the arresters from the line poles to the transformer poles, but from all of the information obtainable, some of which is set forth under a later heading in this paper, it is estimated that the reduction of 59 per cent in fuses blown corresponding to the removal of 30 per cent of the terminal boards can be allotted to the several contributing causes about as follows:

	Per cent	Per cent of total
Removal of terminal boards....................	18	30
Increasing the ratio of arresters to transformers....	10	20
Moving arresters from line poles to transformer poles	31	50
	59	100

If this estimate is approximately correct, it means that the amount of trouble from lightning, on a system with all the terminal boards removed and with lightning arresters equal in number to the transformers and installed on the line poles,

would be reduced about one-half by moving the lightning arresters from the line poles to the transformer poles.

XVIII—Comparison of Several Classes of Protection

Class A and B protection both include transformers having lightning arresters on the same pole. They differ, however, in that class A transformers are all in a segregated area in which each transformer is similarly protected, while the transformers of the class B protection may be surrounded by other transformers of class C protection, that is, without arresters on the same poles. Fig. 11 indicates that according to the record of burn-outs, class A is appreciably better than class B. Fig. 12, showing the record of fuses blown, indicates that class B is considerably better than class A. This latter difference is probably accounted for largely by the rule above mentioned, according to which transformers above 3 kw. capacity were protected by an arrester on the same pole, while the smaller transformers were not so protected. Class B protection, therefore, consists of a selected lot of transformers from which the smaller, or more vulnerable sizes are largely excluded. This is shown by Table II, which indicates that 21 per cent of the transformers in class B protection were below five kw., while for class A protection this figure was 35 per cent.

If the improvement of class A protection over class B, as indicated in Fig. 11, correctly represents their relative merits, then these conditions must be due to the larger number of arresters per square mile, or per mile of line, for class A protection as compared with class B. A reference to Table I shows that there are about ten times as many transformers per square mile for class A protection as for class B. These figures indicate that the installation of an arrester on a transformer pole does not give perfect or complete protection, but that the protection is considerably improved by other arresters on neighboring poles. This means that widely separated transformers along a long line, or isolated at the end of a line, if supplying important service should be protected by installing other arresters in the vicinity in addition to those on the transformer pole.

The figures in Table II for transformers above 15 kw. also show by the large percentage of these transformers the operation of the rules under heading XIII.

It is very evident from Figs. 11 and 12, as well as from several of the tables, that classes A and B protection are both consid-

erably better than class C. Table VIII indicates that the percentage of fuses blown for class A is less than one-third of that of class C, while for the transformer burn-outs the ratio is about one to six.

XIX—Analysis of Class C Protection

As stated earlier in the paper, classes B and C protection cover all of the transformers outside of the 100 per cent areas

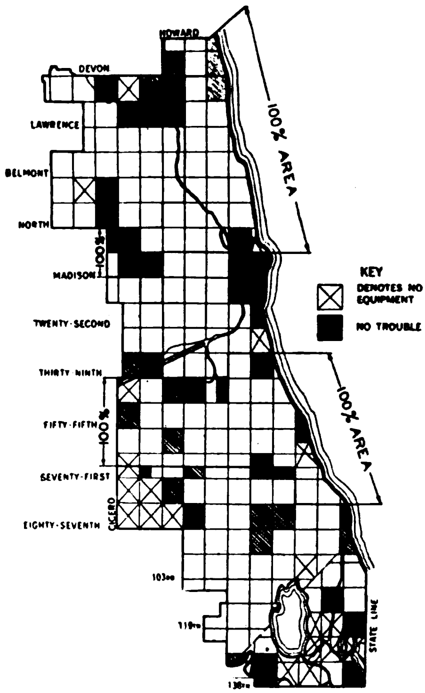


Fig. 18—Map Showing Sections (Square Miles) which Were Entirely Free from Lightning Troubles During 1915

or class A protection. If the transformers included in class B protection are for the moment ignored then the arresters installed for class B protection can be considered, relative to the class C transformers, as being installed on the line poles.

For the purpose of getting a general view of class C protection, Figs. 18 and 19 have been prepared. The former shows by the shading, with the section (*i.e.* square mile) as a unit, the areas in which there was no transformer trouble caused by lightning during the year 1915. Excluding the sections in which there are

no transformers, it is found that within the 100 per cent areas 23 per cent of the total was entirely without trouble, while outside of the 100 per cent areas the corresponding figure was 26 per cent. These figures are so close that one can reasonably conclude that the entire absence of lightning trouble from extended contiguous areas indicates absence of lightning disturbances rather than perfection of the protection. This also means that the fact, that a comparatively few lightning arresters of

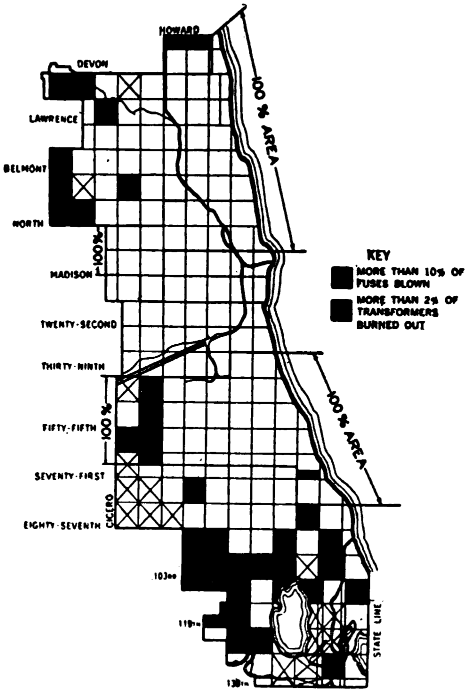


Fig. 19—Map Showing Sections (Square Miles) in which the Troubles from Lightning Were Several Times the Average

any particular type have passed through an entire season without any trouble on the line or apparatus which they protected, is not to be considered as proof that the arresters are of value. It is probable that the absence of trouble may have been due to the absence of lightning disturbances at these particular locations.

Fig. 19 shows, by the shading, the areas in which transformer troubles due to lightning in 1915 were several times the average. Comparing the percentage which these shaded areas bear to the total in the same manner as for Fig. 18, we find that the

areas showing the fuses blown in Fig. 9 are 6 per cent and 28 per cent respectively for the class A areas and for the rest of the city. The similar figures for transformers burned out are 13 per cent and 33 per cent respectively. When considered with the results from Fig. 18, these figures appear to indicate that lightning arresters protect the transformers against a large fraction of the lightning strokes, and that the rest of the strokes, which are probably of a very high frequency and large volume, are beyond the capacity of the arrester.

By comparing the shaded areas on Fig. 19 with a map showing the number of transformers in each section, it can be noted that the shaded sections outside the 100 per cent areas are, in general, the sections in which the number of transformers per square mile is small. An attempt has been made to plot a curve show-

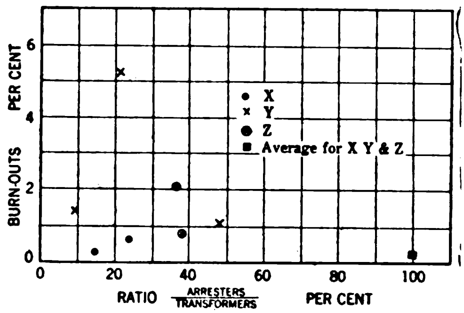


FIG. 20—DIAGRAM SHOWING FOR CLASS C PROTECTION THE RELATION BETWEEN THE RATIO OF ARRESTERS TO TRANSFORMERS AND THE TRANSFORMER BURN-OUTS

ing the variation of lightning trouble with the ratio of arresters to transformers, as shown in Figs. 20 and 21. The points in Fig. 21, showing the fuses blown, almost result in a curve. One point, however, is almost off the scale. This is the result of the storm of August 16th and if this particular storm is eliminated from the record because of its nature, before plotting results, then the storm of May 15th should also be omitted. The latter storm, however, affects other points so that the final result is not materially better than Fig. 21. In a general way, the conclusion can be drawn from this figure, that increasing the number of arresters reduces the percentage of fuses blown; that is, it improves the lightning protection. Taken in conjunction with the previous figure, the points on Fig. 21 appear to indicate that the installation of camparatively few arresters on a line will make an appreciable improvement in the lightning protection.

On Fig. 20 the points are so scattered that it is quite impossible to draw a line which would fairly represent average values. It is probable, however, that a part of this difficulty may be due to differences in the protective values of the several types of arresters.

Taking the several conclusions into consideration, it appears that, starting with the assumptions, (1) that lightning strokes cover a wide range of frequency, and (2) that a lightning arrester acts like a pop-valve rather than like an umbrella, the behavior of the lightning arresters during a thunder storm, may perhaps, be described as follows. Some of the lightning strokes are of comparatively low frequency and moderate volume, so that an

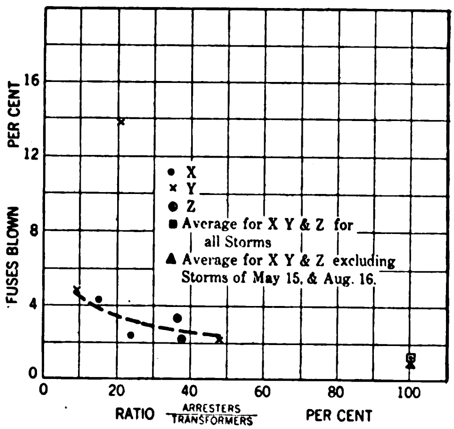


FIG. 21—DIAGRAM SHOWING FOR CLASS C PROTECTION THE RELATION BETWEEN THE RATIO OF ARRESTERS TO TRANSFORMERS AND THE PRIMARY FUSES BLOWN

arrester placed anywhere along the portion of the line affected by the stroke will protect the transformers. This type of stroke is the only kind that is seriously affected by the old fashioned scheme of scattering a few arresters along the line poles.

For strokes of higher frequency, it becomes necessary to have the arresters nearer the transformers, and this may be accomplished in part by installing an arrester on the pole next adjacent to each transformer. This results in a considerable improvement by the elimination of strokes of moderately high frequency, and also of the lower frequency strokes that are of too great volume to be discharged by a single arrester. For strokes of very high frequency, the arrester on the pole next adjacent to the trans-

former is no longer sufficient, and the arresters must be placed immediately alongside the transformer. This eliminates a still further percentage of the lightning strokes from the list that cause damage. There still remain strokes of such high frequency and volume that a single arrester on the transformer poles becomes inadequate on account of its limited discharge capacity. This may account for the damage done to the transformers that are so protected.

Where the transformers are located at some considerable distance along a line, or at the end of a long line, the indications are that a single arrester on the transformer pole will again prove inadequate, and that in order to secure the best protection the rules should require, in addition, a certain maximum distance (not yet determined) between arresters, so as to protect against the lightning strokes of moderate frequency and considerable volume, which cannot be discharged by a single arrester and which are apparently a fair proportion of the total number of strokes.

One of the causes of the difficulty in attempting to secure average results from lightning conditions is well illustrated in Fig. 10. Upon making a critical examination of this map it will be noted that within the four sections adjacent to 111th and State Sts., there were five burned out transformers and 24 blown fuses, or a ratio of 1 to 4.8, while in the four square miles adjacent to 95th St. and Ashland Ave., there were 16 burn-outs and 14 blown fuses, or a ratio of 1 to 0.9. At the former location it appears that there was a large number of strokes of lightning of moderate frequency and volume so that only 20 per cent of the total number of troubles resulted in burned out transformers. At the latter location there was apparently a group of very high-frequency discharges of considerable volume as indicated by the fact that over one-half of the transformer troubles resulted in burn-outs.

Similar evidence of erratic behavior of the lightning can be seen in the storm of May 15th, shown in Fig. 9. In this storm it will be noted that several transformers burned out near 55th St. and Crawford Ave., which were several miles distant from any other lightning trouble. The two burn-outs near 63rd St. and Crawford Ave., were on the same pole, one transformer, burning out in the early morning, was replaced by another during the day and was again burned out by lightning during the evening. In this case there was an arrester on the same pole. If one were inclined to draw conclusions from isolated cases, it

TABLE XII.

SUMMARY OF RESULTS WITH CLASS C PROTECTION. ARRANGED BY AREAS.

Type of arrester	X			Y				Z		
Area No.	2	10	Total	4	11	20+ 21	Total	9+ 12	19	Total
No. of transformers	394	824	1218	1504	746	634	2884	1142	1054	2196
" arresters*	60	198	258	136	358	131	625	436	386	822
Ratio $\frac{\text{arresters}}{\text{transformers}}$ per cent	15.2	24.0	21.2	9.0	48.0	20.6	21.6	38.2	36.6	37.5
Burn-outs No.	1	5	6	21	8	33	62	8	22	30
" per cent	0.25	0.61	0.49	1.40	1.07	5.2	2.1	0.70	2.08	1.37
Fuses blown No.	16	19	35	72	16	88	176	25	35	60
" " per cent	4.1	2.3	2.9	4.8	2.15	13.9	6.1	2.2	3.32	2.74
Transformers below 5 kw. per cent	56	46	49	62	47	76	60	33	71	51

*Same as *B* transformers.

might be concluded from this particular example that the presence of a lightning arrester on a transformer pole is a hazard.

On Fig. 9 there can also be noted, in the northern part of the city, a large number of fuses blown without any transformer burn-outs in the immediate vicinity. In particular, there is one group of such cases near Western & Lawrence Aves. It would, of course, be very interesting to learn whether this group of primary fuses were all blown by one stroke of lightning, or by a number of successive strokes. Such information is very difficult if not impossible to obtain.

XX—Conclusions

As a result of the experience in 1915, the rule under heading XIII was again altered last December, so as to require the installation of a lightning arrester with each transformer thereafter installed, regardless of its size or use. Later it was also decided to extend this rule to all transformers now installed having the class C protection. This is equivalent to stating that the 100 per cent areas are to be extended so as to cover the entire city. This work is now progressing as fast as the deliveries of lightning arresters will permit, and will probably be completed before the presentation of this paper. These changes in the rules were made on account of the improvement in service, which in the light of experience, might reasonably be expected. The net result of the increase in the number of arresters will be an increase in the annual charges against the system of distribution, and as the saving in repairs to transformers is estimated to be not more than about two-thirds of the interest, depreciation, maintenance, etc., of the arresters, the additional expense must, therefore, be charged against improved service.*

An attempt has been made to set forth, during the discussion of the results, such conclusions as could be most readily drawn from the facts submitted. For convenience, however, these conclusions, together with others that appear to be warranted by experience, may be summarized as follows:

1. The transformer troubles during lightning storms may be reduced: (a) by the removal of the transformer primary terminal boards. (b) By the installation of lightning arresters.

*The calculations on which the above conclusion is based, are given in greater detail in a paper entitled, "Lightning Protection for Transformers on 4000-Volt Distributing Circuits," read before the National Electric Light Association at its convention in Chicago May 22nd to May 26th, 1916.

2. Lightning arresters installed on the transformer poles are considerably more effective than if installed on the line poles.

3. When the lightning arresters are confined to the line poles, the protection against lightning is improved by increasing the number of arresters.

4. Whether the lightning arresters are on the line poles or on the transformer poles, the protection appears to be improved by an increase in the number of arresters per square mile or per mile of line.

5. Even in the most severe lightning storms, which apparently cover a given territory quite completely, there will be numerous extended areas within this territory which will be entirely free from lightning disturbances.

6. While a lightning arrester on the same pole with each transformer appears to be quite adequate protection in a region where the transformers are reasonably close together, the protection appears to be inadequate where the transformers are separated by distances ranging above (say) 2000 ft. (609.6 m.)

7. There is no serious difficulty in devising forms of safe construction for installing lightning arresters on the transformer poles. The construction is considerably simplified by the use of self-contained arresters which do not require inspection.

8. The modern types of arresters comply with the specification that a protective device should be less subject to trouble than the apparatus which it protects.

9. The modern types of lightning arresters are so free from trouble that the installation of a fuse in series with the arrester, for the purpose of disconnecting the arrester in case of trouble, is not warranted.

10. Absolute immunity from lightning troubles cannot be secured by an installation of lightning arresters.

11. For the conditions in Chicago the installation of lightning arresters for the protection of transformers is not warranted by the saving in the cost of repairs to transformers, and can be justified only as a means for improving the quality of the service.

12. Great care should be used in attempting to draw general conclusions from the experience obtained from a few arresters, or during a single season or from a limited area.

13. The use of the several schemes for the improvement of the lightning protection that are herein described can reasonably be expected to remove at least 90 per cent of the lightning troubles formerly experienced.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

PROTECTION OF HIGH-VOLTAGE DISTRIBUTION SYSTEMS BY ISOLATING TRANSFORMERS

BY O. O. RIDER

ABSTRACT OF PAPER

This paper calls attention to the practicability of localizing line disturbances by means of transformers. Application is made to High Voltage Distribution Systems serving the rural communities which results in an inter-connected net work of overhead lines.

IN THE generation, transmission and distribution of electricity there is growing the application of intermediate voltages for the supply of energy to the smaller communities and isolated industrial centers, forming a net-work of high-voltage distribution with characteristics in operation and maintenance that present new problems and require plans for protection differing from those on the low-voltage system used in urban distribution. This development applies more particularly in those sections of the country where the population is generally distributed, such as found in the Middle West.

In choosing an electrical pressure for this work, 33,000 volts has been found to be the highest practicable voltage for pin type construction, and at the same time a voltage sufficiently low from which small amounts of power can be supplied economically to meet the growing commercial needs. It also appears that a system operating at this voltage is the most suitable intermediate step between very high voltages for delivery of large blocks of power over long distance, and the low-voltage system ordinarily used for distribution in the larger cities.

In the operation of such a system one requirement is at all times preeminent; namely, supplying continuous service over three wires. The non-grounded neutral system is used which permits service being maintained under conditions of accidental ground on one phase. This greatly lessens the chances of interruption by short-circuit but, as is well-known, it produces more surges for a longer time during an arcing ground than the

Manuscript of this paper was received April 25, 1916.

grounded neutral system. Delta connection of transformers is used.

The chief aim of this paper is to call attention to the improved operation obtained from isolating transformers on a non-grounded neutral system. Other attending factors affecting continuity of service are important and are receiving careful attention, but are not within the scope of this article.

Localization of Abnormal Conditions

The localization of disturbances caused by single phase accidental grounds is a matter of great concern, especially in high-voltage systems which extend over a large territory. A single defective insulator which grounds a phase affects the entire system which is metallically interconnected. Small or local electric storms often develop in one section and cause this hazard to service in every other section. When the storm is general the entire system is subjected to these abnormal conditions from the time the storm enters the zone of electrical supply until it passes the remote sections supplied from branch lines. The troubles are multiplied accordingly.

In the growth of these large interurban systems smallpower plants are sometimes connected where the insulation of the line is not up to the highest standard, due to one cause or another. Also, where systems are connected together for interchange of power, the possibility of trouble from accidental arcing ground is multiplied by this extension of territory covered by the two systems. In many such cases it is undesirable to use automatic circuit-breakers at the connecting points to disconnect the power when the trouble is due only to unbalanced electrostatic conditions of the phases.

In these cases isolating transformers between the systems can be advantageously used. These transformers may be either 1 to 1 ratio or they may step down the power to a lower distributing voltage and up again to the transmission voltage, according to the attending conditions. It is desirable, of course, to locate these stations where local distributing service is required. Where a section is to be isolated by this means an added advantage comes in the use of standard regulators for the maintenance of voltage. This plan of regulation will be found to care for voltage conditions at intermediate points and eliminates the necessity of supplying a great number of regulators for the small communities.

With these isolating transformers the disturbance of an accidental arcing ground on one section is confined entirely to that section and still power is transmitted without interference to and from all other sections as under normal conditions.

On each section where an accidental arcing ground takes place the proper protective devices should be used to protect from abnormal voltages. The arcing ground suppressor has been recommended and used. It is not the object of this article to treat these details but simply to record the successful use of the isolating transformer which limits the disturbances to one part of a large system.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

(*Subject to final revision for the Transactions.*)

MEGGER AND OTHER TESTS ON SUSPENSION INSULATORS

BY F. L. HUNT

ABSTRACT OF PAPER

This paper gives the results of megger tests made on disk insulators on a 66,000-volt transmission line in central Massachusetts after 2.5 years' operation. In one lot of 4410 insulators tested 9.77 per cent tested less than 2000 megohms. The percentage of failures in different positions in the string is given on both strain and suspension towers. The actual cost of making these tests under different conditions of weather and of service requirements is given per insulator on the line, per bad insulator and per tower. The cost per insulator on the line, of testing only, varied from 7.3 cents to 11 cents. The cost of replacing bad insulators was 74.5 cents per bad insulator, not including the cost of the replacing insulator.

Laboratory tests made on 30 of the bad insulators taken from the line showed that those which measured very low by the megger fail on 60-cycle tests much below spark-over value while those with medium high resistance may reach flash-over value and then puncture within one minute. Some insulators which show infinite resistance by the megger, and which withstand arc-over potential at 60 cycles, will fail under high-frequency test immediately.

DURING the latter part of 1915, megger tests were made on all the insulators on one circuit, and part of the insulators on the other circuit, on nineteen miles of 66,000-volt, double circuit transmission line in central Massachusetts. These circuits are supported on galvanized steel towers, three wires to each circuit spaced 10 ft. (3m.) apart vertically, the two circuits spaced 18 ft. (5.4 m.) apart horizontally, the bottom wire 45 ft. (13.7 m.) from the ground, average span, 550 ft. (167.6 m.)

The total number of insulators tested on this line was 4410. These were suspension type insulators hung with four per wire on suspension towers and five per wire on dead end towers. Numbering the insulators from 1 to 5, beginning at the cross arm, the number of failures in each position is shown in the tabulation given below.

Manuscript of this paper was received April 25, 1916.

Strain towers.					
Unit number	1	2	3	4	5
Total number	486	486	486	486	486
Total damaged	50	43	47	51	64
Per cent damaged	10.28	8.84	9.67	10.49	13.16
Standard suspension towers.					
Unit number	1	2	3	4	
Total number	495	495	495	495	......
Total damaged	61	32	47	36	......
Per cent damaged	12.32	6.46	9.49	7.27	......

The above results seem to indicate that there was no logical relation between the number of failures of the insulators in any given position and their distance from the conductors.

Cost of Tests

It was necessary in testing these insulators to take one circuit at a time, so that all the towers had to be gone over twice. Of the total number of 4410 insulators tested, there were 2430 dead end insulators, of which 255, or 10.5 per cent, were bad; and 1980 suspension insulators, of which 176, or 8.9 per cent were bad, as indicated by megger tests above.

A crew of three men was used in making the tests and twenty week days and twelve Sundays were consumed.

The total cost of the tests, including cost of transportation, was $424.69.

The insulators on one circuit were tested on 180 towers and on the other circuit on 69 towers. The cost per tower per circuit on the first 180 towers was $1.97. The cost per tower per circuit on the 69 towers was $1.02 each. The average cost of the whole job was therefore $1.70 per tower per circuit, and 9.6 cents per insulator tested, where only one circuit could be tested at a time with the other circuit alive during the testing.

The variation in cost per tower in the two parts of the job was due almost entirely to the difference in weather conditions. In the first case the weather was cold and the insulators were covered with frost, so that the work could not be started until about ten o'clock in the morning. The men were also stopped several times by rain, so that considerable time was lost, and this section of the testing included most of the Sunday work.

The total cost of replacing the 431 bad insulators was $322.27 or 7. 3 cents per insulator on the line and 74.5 cents per bad in-

sulator. The total labor cost of testing and replacing bad insulators on the line was therefore 16.9 cents per insulator of the total number or $1.73 per bad insulator. This does not cover the cost of new insulators. If it had been necessary to pay for new insulators, the total cost per bad insulator would have been three times the original cost.

These insulators were in use less than three years, having been installed in the early part of 1913, put into operation in May, 1913, and tested in the latter part of 1915.

A recent inquiry made from an insulator manufacturing company brought out the fact that they would add 4 cents per disk to the price of the insulators in order to cover the cost to them of putting their insulators through a high-frequency test before shipment. If such a test would have taken out the insulators that have failed during the first 2.5 years of operation, it would appear that 4 cents additional in the initial price would have been a good investment, since the cost of testing and replacing bad insulators has amounted to 16.9 cents per disk on the line.

Another section of line of about the same length upon which insulators of a different design had been installed, was tested at a cost of 7.3 cents per insulator, which is slightly less than the cost per insulator in the first case. Due to the fact that both circuits were tested at the same time, each tower had to be climbed but once. The insulators in this second case showed less than one per cent of failures and, on this account, it was not considered necessary to replace the bad insulators, since there was no case in which more than one bad insulator occurred in one string.

LABORATORY TESTS

To get definite information regarding the nature of the faults in the insulators they were shipped to a laboratory where the following tests were made with the co-operation of Mr. E. E. F. Creighton and Mr. P. E. Hosegood.

The total number of insulators selected was 40. Thirty-five of these were taken from the line and five were new insulators. Twenty-one measured below 10 megohms, eight measured 22 to 52 megohms, one measured 220 megohms, five from the line measured infinity, and the five new insulators measured infinity, making up the total of 40.

Test 1. Eleven of the insulators which meggered below 10 megohms had 60-cycle voltage gradually applied to them until they punctured. Not one of them reached flash-over value.

The voltage was very gradually raised and the lowest puncture voltage was 22 kv., the highest was 52 kv., and the average of the 11 was 39 kv.

Test 2. Seven of the insulators which measured between 22 and 52 megohms and the one measuring 220 megohms had arc-over voltage applied to them until they punctured. Four of them punctured immediately, 2 of them punctured in one second, one in four seconds, and one in thirty seconds. There is no relation between the megger readings and the time of puncture.

Test 3. In this test a constant voltage far below the arc-over value was applied until puncture occurred. Seven insulators measuring below 10 megohms were tested. The first five had applied to them 20 kv. They punctured in from one to thirty seconds. Two more were tested at 15 kv., one puncturing in one second, the other in six seconds. There is no consistency between the puncture voltage and the megger readings as sufficiently illustrated by the last test. In this test one of the insulators measured three megohms and the other below one megohm, but the higher resistance insulator took one second to puncture whereas the other insulator with lower resistance took six seconds to puncture.

Test 4. Spark-over voltage of 60 cycles was applied to the 10 insulators which measured infinity. Three of these punctured in less than 45 seconds. This is 30 per cent loss on 60 cycles.

Test 5. The remaining seven insulators which had shown O.K. on a minute's test on 60 cycles at flash-over voltage, were next tested on the oscillator using a frequency of approximately 200,000 cycles per second. Flash-over voltage only was applied. Two of the seven punctured in less than one minute. This is again about 30 per cent of the insulators that were left. The remaining five withstood super-spark potential of 120 kv. for 10 seconds each.

Conclusions. The results of these tests are similar to others that have been made and show, first, that insulators which measure very low will fail almost immediately on a 60-cycle test voltage, much less than spark-over value. Insulators with medium high resistance may reach flash-over value of potential and will puncture within a minute. Insulators of infinite megger reading may have faults developed by the arc-over potential within one minute's application. After the faulty insulators have been eliminated by the 60-cycle test, still further faults are found by the oscillator.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

EXPERIENCES IN TESTING PORCELAIN

BY E. E. F. CREIGHTON

ABSTRACT OF PAPER

The paper gives the results of numerous experiences in testing porcelain insulators particularly in regard to porosity, absorption of water, surface leakage and dielectric losses. Considerable energy is required to drive moisture out of a porous insulator and it has been found best to restrict the oscillator testing to dry porcelain, whereas the wetter the porcelain the more effective is the 60-cycle test.

THE FOLLOWING experiences in testing porcelain insulators and the resultant deductions are given as an addition to the development of the relating science and practice.

For the present purposes the resistances of insulators may be classified as follows.

1. Distributed resistance due to water in pores.
2. Concentrated resistance due to water in cracks.
3. Surface leakage (external).
4. Dielectric losses (equivalent resistance).

I—DISTRIBUTED INTERNAL RESISTANCE

Wet-process porcelains have been examined having a porosity much less than 0.01 of one per cent by weight. Dry-process porcelains have a usual porosity of 1 per cent to 2 per cent. The pores are fissures, visible to the naked eye if a stain is used to color them. These porcelains take up water rapidly simply by soaking an hour. As the porosity decreases the water meets more and more opposition to its entrance by the back pressure of the air entrapped in the pores. Under conditions easily reproducible in the laboratory a porous body covered with a liquid will remain perfectly quiescent for a minute or two while the liquid is soaking in from every side. Finally the internal air pressure becomes great enough to break through the wall of water and a stream of bubbles will break forth. Where the porosity is very small the porcelain, soaked for months in a bath of water, refuses to take up the water. Still this same insulator on a transmission

Manuscript of this paper was received April 25, 1916.

circuit will take up sufficient water to reduce its internal leakage resistance to as low as 300 megohms. This difference in absorption is due to the changes in temperature. An increase in temperature causes an expansion of air which drives some of it out. Subsequently it breathes in moist air and moisture. Each temperature change causes a deeper penetration until, by fractional distillation, there is a conducting path between surfaces. The necessary period in such a case may extend over several months.

Such slightly porous and wet insulators still retain some value as insulators but they are a menace since they will fail rapidly under an increase in potential. Such an increase may take place suddenly by the failure of another unit in series with it.

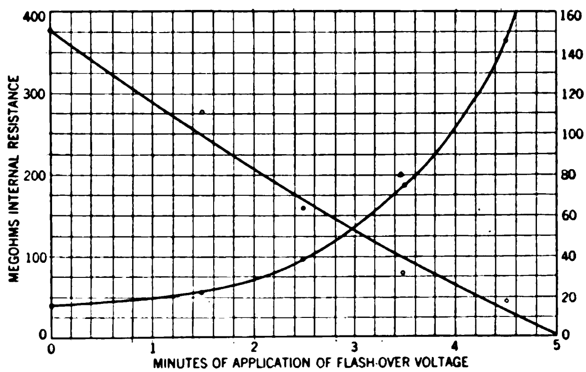


FIG. 1

A rare case of porosity was studied. Fig. 1 shows the relation of internal resistance and wattage loss, both relative to the time. On the application of 60-cycle potential, at flash-over value, the resistance gradually decreased from 380 megohms to zero in five minutes. The wattage rose from 16 watts, slowly at first then with a rapid increase as the water and porcelain were heated up by the ohmic loss ($E^2 \div R$). At the end of 4.5 minutes the loss was 145 watts. At the end of 4.5 minutes the total energy given to the insulator was 14,000 joules. An unknown portion of this energy was radiated and conducted away during the four periods of interruption of potential test, to measure the ohmic resistance. Calculating the maximum possible temperature, from the energy loss and the specific heat, it must have been less than 80 deg. cent. at the instant of puncture of the porcelain. The

estimated energy was 20,000 joules including the heat conducted and radiated away. A continuous application of potential would have shortened the period before puncture occurred. It is seldom that a porous insulator withstands application of flash-over potential for even one minute.

With even distribution of moisture throughout the head of the insulator and taking 140 cu. cm. as the volume under stress, the average energy per cubic centimeter to cause puncture was approximately 143 joules.

In testing such porcelain for porosity the methods which have been previously recommended are inadequate. The following precautions are taken to get greater accuracy.

1. Evacuation of the porcelain at a micron of pressure or less is carried on for about eight hours.

2. The air is removed from pure water by boiling and evacuation.

3. Water is poured over the porcelain samples without breaking the seal.

4. Subsequently the seal is broken and the samples are allowed to soak a week in water.

5. The surface of the samples is carefully and quickly dried and the weight taken. The error of weighing is not greater than 1 in 100,000.

On samples of low porosity this method may put five-fold more moisture in the pores than the method previously recommended.

II—Concentrated Resistance

Concentrated moisture in cracks or spots causes a rapid rise in temperature and consequently there lapses a brief period before puncture. A crack a mil wide (0.0025 cm.) 2 cm. long and 2 cm. deep would have a volume of 0.01 cu. cm. and the time to cause puncture at flash-over voltages might be no greater than 0.01 second, assuming the specific resistance of the water to be one million ohms. At any rate the period would be brief.

As a rough method of analysis it may be assumed in general that insulators are porous which on measuring less than 600 megohms, withstand for many seconds a potential nearly equal to flash-over value. On the contrary, insulators which puncture quickly are either cracked or possibly porous in a local spot.

III—Surface Leakage

The resistance to surface leakage will depend, evidently, on the thickness and nature of the deposited material on the surface

of the insulator. Using a thin layer of washed clay and varying the humidity, the curves of resistance versus humidity are given in Fig. 2.

The following is a record of one insulator of several which were coated with dust (porcelain slip) and placed in a wooden box where the humidity was gradually increased to a high value and then decreased. The total period of test was 20 days. Surface resistance tests were made from time to time. Fig. 2 shows the relation of surface resistance to humidity in the box. Naturally there was a little lower resistance on increasing the humidity than on decreasing it due to the fact that the humidity was introduced by heating water in a receptacle placed underneath the box and connected to it by means of a tube. The variation in resistance on the up-curve and down-curve, however, is not very great except at extremely high humidities where there is comparatively little interest. This curve may be considered the extreme condition in dusty countries where there is a long dry season so far as rain is concerned but where fogs and dews take place. If an insulator is in service, the leakages of current over the surface would give sufficient heating effect to prevent the lowering of the resistance to the very low value obtained in these tests. These conditions might exist, however, where the line is out of service for testing purposes.

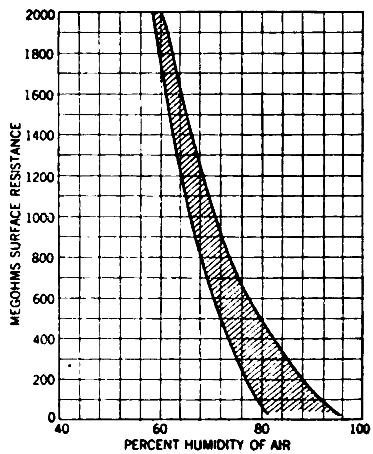


FIG. 2

Naturally the condensation of moisture on a surface of this kind depends on differences of temperature between the insulator surface and the surrounding atmosphere and also upon the humidity of the atmosphere. No attempt is made in the tests to take this factor into account but it is of course the condition which appears so prominently at sunrise.

Increasing the size of an insulator does not necessarily increase its resistance. On the contrary, the larger insulators, due to their shapes, usually have a less surface resistance than the smaller insulators, other things being equal. The tests correspond with the theoretical calculations.

A little salt or carbon added to the film of dust, lowers the surface resistance below the values given in Fig. 2 at the same degree of humidity.

The following tests were made to determine how long it takes a dusty insulator to dry off. A large pin-type telephone insulator was coated with porcelain slip, containing no free acid or alkali. The resistance of the surface coating of clay was initially 88,000 ohms. The insulator was allowed to stand in an atmosphere which had a humidity of 36 per cent and a temperature of 23 deg. cent. The porcelain slip was at the same temperature as the room. After half an hour the moisture had sufficiently dried off the surface of the insulator to give 300 megohms resistance. At the end of another half-hour, making a total of one hour, the resistance had risen to 2000 megohms.

IV—Dielectric Losses

The losses in solid porcelain, for intermittent wave trains, are negligible. The dielectric hysteresis of air is too small to measure. However, if the entrapped air in porcelain is strained beyond its electric strength it forms hot corona, which not only destroys its own dielectric strength but also damages the cell walls of porcelain which enclose it.

The Practise of Testing with the Oscillator

Factory practise calls for oscillator tests on the porcelain parts as they come from the furnace. The parts should not be partially immersed in water for the tests as is usually done in testing at 60 cycles. Caps and pins may be loosely applied to the porcelain, and the corona at high frequency will satisfactorily fill the intervening air spaces. The high frequency and the higher test voltage obtained in the oscillator method of testing finds, on an average, 8 per cent more faulty porcelain than the 60-cycle method. Occasionally where porcelain is only slightly porous and dry it easily withstands the 60-cycle test and the oscillator has removed as much as 25 per cent of the number that have passed the 60-cycle test. The 60-cycle method becomes more effective if the porcelain is porous and wet. For this reason in testing line insulators the oscillator as recommended in a previous paper must be somewhat modified. It is necessary to make the tests first with 60 cycles to eliminate the wet porous insulators; then with high frequency to find the dry porous and otherwise weak ones. In applying the 60-cycle test, time

is saved by applying the voltage to all the disks of two strings simultaneously.

It has been shown that the energy necessary to drive out the moisture in a porous insulator is considerable. The oscillator has extremely high power but the wave trains die out quickly. It is, therefore, necessary to restrict the oscillator to the testing of dry porcelain. The wetter the porcelain the more effective the 60-cycle test and the drier the porcelain the less effective the 60-cycle test and the more effective the oscillator test in detecting porous porcelain. Even if there were 100 oscillations in each wave train the potential would be applied only about 1/20 of the time. In other words, the I^2R loss in the leakage of the insulator would be less than 1/20 of what it would be at 60-cycles at the same voltage. Consequently it will take a much longer time to heat up the water in the pores of the porcelain than with an equal 60-cycle voltage.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

A NEW METHOD OF GRADING SUSPENSION INSULATORS

BY R. H. MARVIN

ABSTRACT OF PAPER

Attention is drawn to the known disadvantages of the uneven distribution of voltage in long strings of disks. The general theory showing how the distribution is determined by the various capacities of the units is given. It is shown how the distribution can be improved by grading, or varying the internal capacity of the units.

The proposed method of grading consists in placing flat metal rings on the insulator, around the cap and stud respectively, the porcelain disk being enlarged for this purpose.

A simple method of measuring the voltage distribution is described using a single needle gap.

The results of tests with and without grading are given, the graded strings showing a decidedly better distribution of voltage.

INTRODUCTION

THE UNEVEN distribution of voltage along a string of suspension insulators is well known. With a small number of units this feature is not serious, and scarcely justifies the complication and expense required to overcome it. But with an increasing number of units, the distribution becomes continually poorer. A limit is soon reached where additional units make no appreciable increase in the potential of flash-over. It is believed that any further increase in operating voltages will necessitate a consideration of this problem.

In general, the unit next to the line has the largest proportion of the voltage across it, the succeeding units taking a smaller and smaller amount. This is unsatisfactory for two reasons; the units near the line have to stand an excessive strain, the units near the tower or grounded end have a lower voltage across them than is desirable for efficient service.

A number of plans for improving the voltage distribution have been suggested. These all consist in varying the electrical characteristics of the successive units in a definite manner, and a string of insulators so arranged is said to be graded. The

object of this paper is to describe a new method of grading, and to show some results obtained with it

Before proceeding it is advisable to give a brief discussion of the fundamental principles involved in grading a suspension insulator.

Theory of Grading

The distribution of the impressed voltage along a string of units is determined by the relations among the four groups of capacities involved. (1) The capacity through the porcelain between the cap and stud of each unit, which may be called the internal capacity. (2) The capacities between the metal fittings and the earth or grounded objects. (3) The capacity from a metal fitting on one portion of the string to any other portion of the string. (4) The capacity between the metal fittings and the line wire. In theoretical discussions only the first two groups are usually considered, but experiments indicate that the others have an appreciable effect.

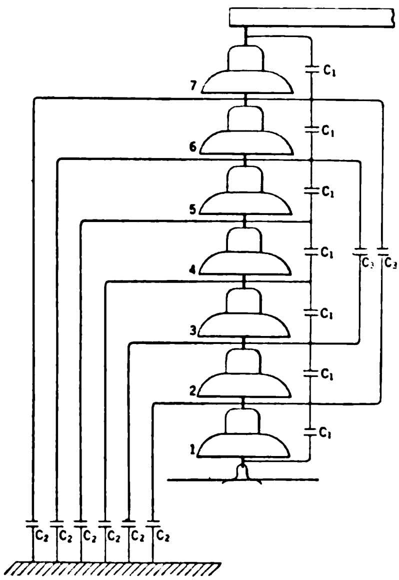


Fig. 1

Considering the first three groups only the capacitances in a string of units may be represented as in Fig. 1. For the sake of clearness, only part of the capacities between the various parts of the string are shown.

It is readily seen that the current to charge all the capacities C_1, C_2 and C_3 must pass through the internal capacity C_1 of unit No. 1. The internal capacity C_1 of unit No. 2, has to supply current to the succeeding C_1 capacities, but has a smaller number of C_2 and C_3 capacities to charge. Consequently the first unit has a higher voltage across it than the second. The same reasoning applies to the other units. It appears, therefore, if we neglect the C_3 capacities, that No. 7, the grounded unit, will have the lowest voltage across it. The capacities C_3 tend, however, to make the voltage across the

middle unit the lowest, so that the total result is that one of of the units near the grounded end, and not the grounded unit, has the lowest voltage across it. This will be seen in the experimental curves to be described later.

The principle of grading consists in varying the internal capacity C_1 from unit to unit, so that the voltage across each unit is kept as nearly as possible the same. This means that the unit next to the line must have the greatest internal capacity, C_1, and successive units, decreasing amounts.

Method of Grading Adopted

To obtain the necessary variation in the capacity from cap to stud, the following plan was devised. Sheet metal rings are placed around the cap and stud where it is desired to increase the internal capacity. By varying the width of these rings, the capacity can be varied over a considerable range. Of course the external capacities C_2 and C_3 of the unit are also varied by this, but not in the same proportion as C_1. To secure a perfectly

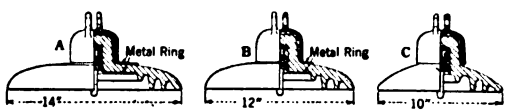


Fig. 2

even distribution of voltage, it would be necessary to have each unit different, entailing great complication, and rendering manufacture very difficult. It was therefore decided to make a compromise, and divide the string into two, three or more groups, each group having different characteristics from the others.

Fig. 2 shows three different sizes of units designed for use in a three group string. On account of the width of the metal rings, it is necessary to increase the diameter of the porcelain so as to give the correct flash-over voltage. The metal rings are stamped or spun out of sheet metal. They are held in place by the cap, and by the cement around the stud. A string would be composed of a certain number of A units next to the line, followed by a number of B units, while the rest of the string to the tower end would consist of the plain C units.

Measurement of the Distribution of Voltage

Before proceeding with the results obtained, it is advisable to give a brief description of the method of investigation.

It is evident that a flash-over test is useless as an indication of the strains at normal voltage, due to the equalizing effect of the corona preceding the spark. Some method must be used in which only the normal voltage is applied. Several very ingenious forms of potentiometers have been devised by Prof. Ryan for this purpose. Conditions, however, did not permit of using one of these, and the following method was therefore devised. While it cannot be considered an exact method due to several inherent sources of error, it is thought to be sufficiently accurate to give a satisfactory idea of the distribution. It has the advantage of being very simple, and requiring very little apparatus.

A small needle gap is provided having the minimum amount of metal in the parts in order to keep the capacity as low as possible, Fig. 3. In our experiments the gap was about ¼ in. (6.3 mm.). This gap is placed across each unit in succession and the total voltage across the string which causes the gap to go over is noted. The gap setting is kept the same throughout the test. See Fig. 4. The discharge across the gap is only the charging current of the insulators, and does not injure the needles, so that the same needles can be used throughout. In general, we wish to know what percentage of the total voltage is impressed on each insulator, and the percentage of the voltage across each unit in terms of that across some particular unit. It was found most convenient to base results on the line unit, as in all our work it showed the greatest voltage.

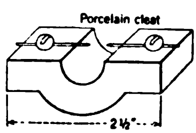


Fig. 3

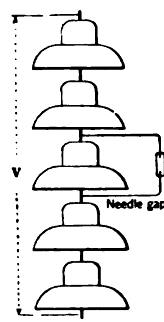


Fig. 4

The units will be numbered from the line towards the grounded end. The line unit being No. 1; the ground unit No. n, or the total number of units. Let v' = spark voltage of needle gap.

$V_1, V_2, V_3, \ldots, V_n$ = total voltage across the string when gap discharges across Nos. 1, 2, 3, etc., respectively.

$v_1, v_2, v_3, \ldots, v_n$ = voltage across units Nos. 1, 2, 3, etc., when total voltage is V_1.

$p_1, p_2, p_3, \ldots, p_n$ = voltage across each unit as a per cent of that across the line unit, No. 1.

$P_1, P_2, P_3, \ldots, P_n$ = per cent of total voltage across each unit.

S = sum of $p_1, p_2, p_3, \ldots, p_n$.

Then the calculations can be arranged as in Table 1.

TABLE I.

Unit No.	v	p	P
1	$v_1 = v'$	$p_1 = 100$	$P_1 = 100\ p_1/S$
2	$v_2 = v'V_1/V_2$	$p_2 = 100\ v_2/v_1 = 100\ V_1/V_2$	$P_2 = 100\ p_2/S$
3	$v_3 = v'V_1/V_3$	$p_3 = 100\ v_3/v_1 = 100\ V_1/V_3$	$P_3 = 100\ p_3/S$
4	$v_4 = v'V_1/V_4$	$p_4 = 100\ v_4/v_1 = 100\ V_1/V_4$	$P_4 = 100\ p_4/S$
n	$v_n = v'V_1/V_n$	$p_n = 100\ v_n/v_1 = 100\ V_1/V_n$	$P_n = 100\ p_n/S$

It will be noticed that if only percentages are required, it is unnecessary to know v', the gap voltage, and the second column may be omitted.

The errors in the method are due to the capacity of the gap and its leads, and the possible effect of surrounding objects on the spark voltage of the gap.

Results of Tests

Experiments were made on strings of 15 units. The method used was to obtain the distribution on the ungraded units, and then observe the change due to grading in various ways. For experimental purposes the effect of the metal rings was readily obtained by painting the porcelain with a conducting varnish. The string was placed outdoors to avoid the effect of the walls of the building. An iron pipe placed horizontally was used to represent the cross-arm, and the string of insulators was suspended vertically from this, the lower end being about 10 ft. (3 m.) from the ground. A clamp was attached to the string, and held a metal pipe to represent the line wire. The frequency used was 60 cycles.

Fig. 5 gives the results of tests on an ungraded string. Curve No. 1 shows the values of p, the percentage that the voltage on each unit is to that on the line unit. If the distribution of voltage were uniform a horizontal line at 100 per cent would be obtained instead of the drooping curve, No. 1. It will be seen that the lower portion of the curve is nearly horizontal and that the fourth unit from the grounded end has the lowest voltage across it. Curve No. 2 gives the distribution of voltage along the string in per cent of the total voltage. Each successive ordinate is obtained by adding the value of P for that unit to the preceding ordinate. A uniform distribution would give the dotted straight line, No. 3.

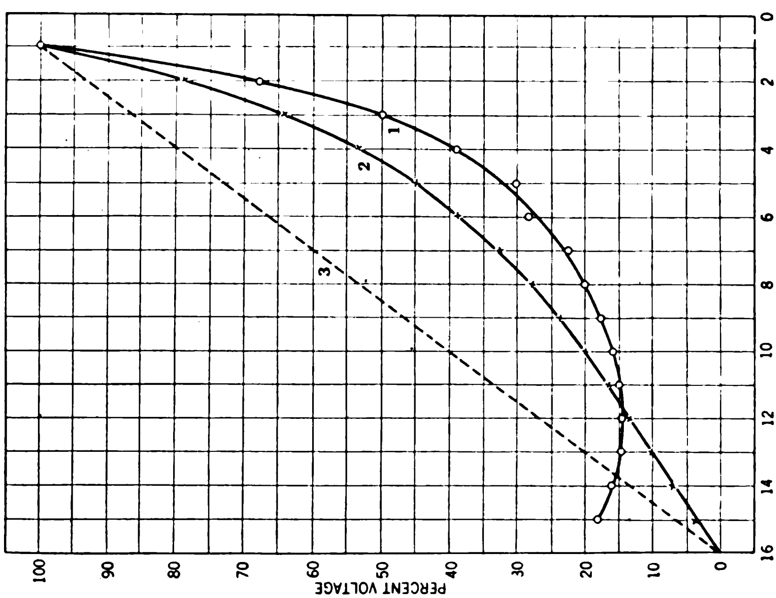


FIG. 5

1—Voltage across each unit in per cent of that across one nearest line
2—Distribution of voltage to ground along string
3—Ideal distribution of voltage to ground along string

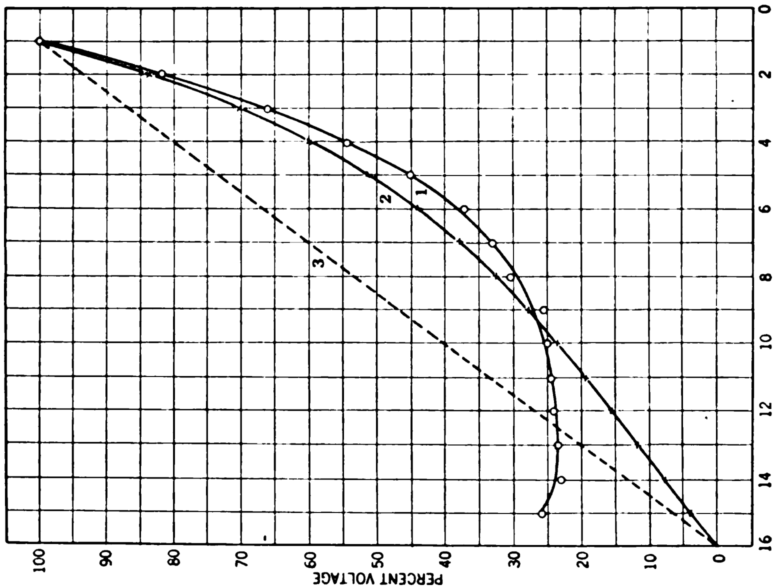


FIG. 6

1—Voltage across each unit in per cent of that across one nearest line
2—Distribution of voltage to ground along string
3—Ideal distribution of voltage to ground along string

Fig. 6 shows similar curves for another type of ungraded unit. In this the internal capacity has a higher ratio to the external capacities. On this account the distribution of voltage is appreciably better, although far from ideal.

Fig. 7 gives the result of grading the type of unit used in the

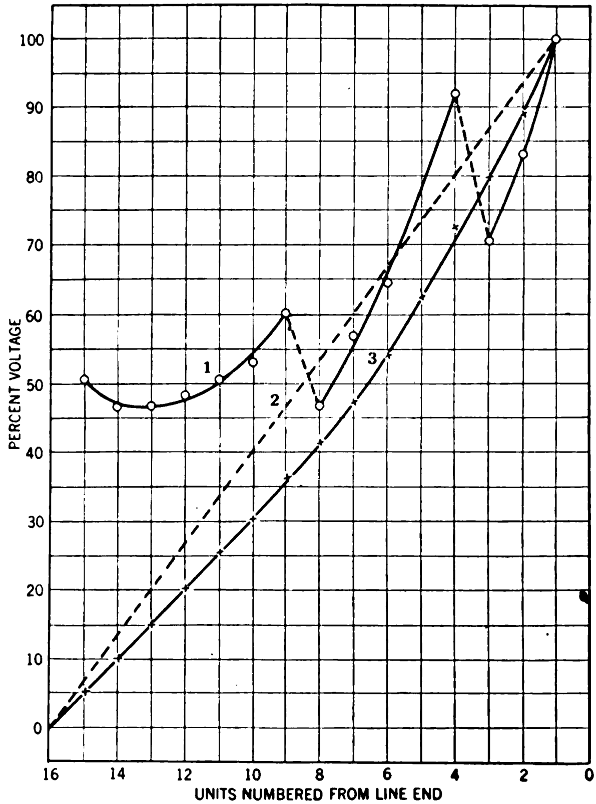


FIG. 7

1—Voltage across each unit in per cent of that across one nearest line
2—Distribution of voltage to ground along string
3—Ideal distribution of voltage to ground along string

tests of Fig. 6. In this case the three units next to the line had the largest conducting disks, and a high internal capacity. The next five units had a somewhat smaller capacity. The last seven units had no coatings. Instead of uniform curves, the result is a broken line formed by joining the curves due to each group. Comparing this with Fig. 6, a great improvement is

evident. Curve 1 is greatly raised toward the horizontal, and curve 3 is nearer curve 2, which represents perfection.

The efficiency of the lowest unit compared to the line unit has been brought from 23.5 per cent up to 46.5 per cent, or nearly doubled. This results in reducing the proportion of the total voltage on the line unit from 16.5 per cent to 11 per cent, a reduction of 27 per cent.

Conclusion

The experiments described in this paper are only preliminary, and much further investigation is desirable. It is felt, however, that the results obtained indicate the value of this method of grading where the voltage is such as to require the use of many units.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

EXPERIENCE AND RECENT DEVELOPMENTS IN CENTRAL STATION PROTECTIVE FEATURES

BY N. L. POLLARD AND J. T. LAWSON

ABSTRACT OF PAPER

The protective features described in this paper are some of those now in use on the system of the Public Service Electric Co. which serves a population of about 2,200,000.

The most interesting protective devices and schemes discussed in this paper are as follows:

Aluminum cell arresters; arcing ground suppressor; faulty cable localizer; cable testing; high potential and high frequency testing; generator bus connection scheme; exciter connection scheme; reactors; relays; multi-recorder; insulation resistance recorder; air washers; resistance bulbs and thermo-couples; dampers on air blast transformers; coherer alarm devices; potential indicating devices.

THE ENTIRE territory served by The Public Service Electric Co. comprises three principal divisions; the Northern, Central and Southern, which include the more densely populated sections of the State of New Jersey. Fig. 1 shows a diagram of the transmission system.

The Northern Division consists of eight generating stations having a combined capacity of 148,000 kw. and feeding 33 substations.

The Central Division consists of five generating stations having a combined capacity of 17,800 kw. and feeding 13 substations.

The Southern Division consists of four generating stations having a combined capacity of 32,000 kw. and feeding 17 substations.

In the larger stations, current is generated at 13,200 volts, 3-phase, both 25 and 60 cycles, and in most cases is distributed at that voltage between the various stations and substations, through 260 miles (418.4 km.) of underground cable and 425 miles (683.9 km.) of overhead lines.

In the smaller stations, current is generated at 2400 volts, two-phase, 60 cycles, and distributed locally at that voltage. That part of the current not consumed locally, is stepped up to

Manuscript of this paper was received April 29, 1916.

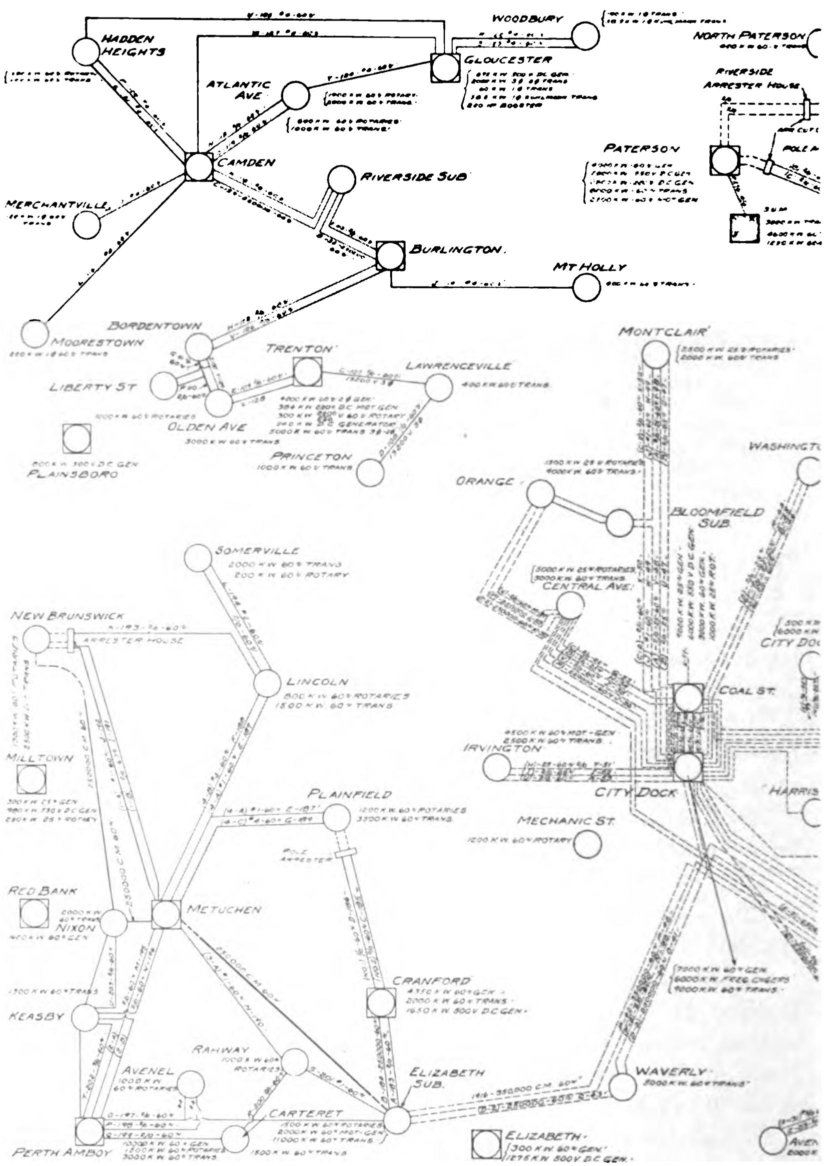
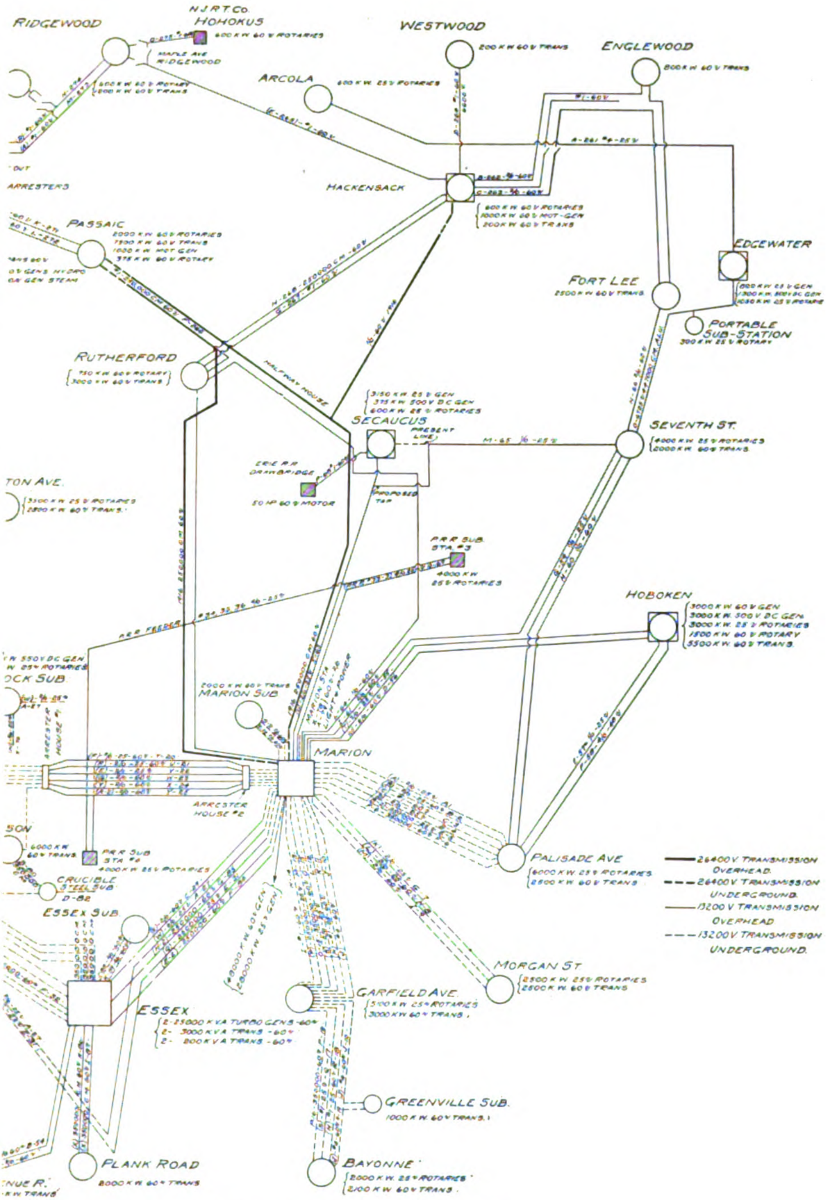


FIG. 1—GENERAL TRANSMISSION SYSTEM



OF THE PUBLIC SERVICE ELECTRIC COMPANY

13,200 volts, three-phase, by means of Scott-connected transformers.

In certain sections our loads have increased so rapidly that it has been found impracticable to take care of any additional load and maintain the proper service at these points. In order to take care of these sections it was found necessary to change some of our transmission lines to 26,400-volts, and to install step-up and step-down transformers with a ratio of two to one.

The method of operation is to run all stations in multiple, which necessarily means that the largest and most economical stations deliver the most output. The older and smaller stations are used at off-peak and as stand-by stations.

Six years ago, in the Northern Division, there were too many cable failures in relation to the mileage. The following table shows the number of shut-downs in the Marion zone since 1910, and a classification of these shut-downs for 1913, 1914, and 1915. A few of the cables are operated either as spare cables, 25 or 60-cyles, and these are included in the total mileage of both the 25 and 60-cycle cables. The total number of line and cable interruptions since 1913 has decreased while the mileage has increased. This was brought about by eliminating as rapidly as possible all equipment that was proved defective and by the use of such safety devices and connection schemes as are described later.

CLASSIFICATION OF TROUBLES.

Classification	1913				1914				1915			
	25 ~		60 ~		25 ~		60 ~		25 ~		60 ~	
	No	%	No.	%	No.	%	No.	%	No.	%	No.	%
Insulator failures	12	22	30	20	15	19	14	13	3	6	6	5
Cable failures	2	4	21	14	4	5	12	10	14	26	18	15
Central station app.	3	5	4	3	1	1	5	4	5	10	3	3
Sub-station app.	2	4	7	5	20	26	11	10	12	23	10	8
Secondary feeders	5	9	23	15	8	10	16	14	..	..	6	5
Operating mistakes	2	4	10	7	2	3	4	4	..	..	5	4
Storms	9	17	16	11	11	14	15	13	8	15	22	19
Outside interference	9	17	22	15	7	9	27	24	5	10	19	16
Mechanical breaks	0	0	0	0	0	0	0	0	0	0	0	0
No apparent cause	10	18	15	10	10	13	9	8	5	10	25	22
Miles cable	83		90		83		121		83		141	
Miles overhead	54		123		54		133		54		144	
Miles total	137		213		137		254		137		285	
Insulator failures per mile		.22		.24		.28		.105		.055		.042
Cable failures per mile		.024		.23		.048		.099		.169		.125

Aluminum Cell Arresters

While the installation of aluminum arresters has made the apparatus trouble disappear almost completely, and as the table shows, the failures of cables have decreased, it has, as might be expected, not given all the desired protection to the cables. The reason for this is probably due to the fact that the surges on the cables are in the form of distributed charges and the potentials rise locally in the cables entirely beyond the protective influence of the arrester.

Upon analyzing these cable failures, it was noticed that the majority of them were caused by faults to ground which later developed into short-circuits. At this time, due consideration was given to the question of grounding the neutral of the system, but after taking all the factors of the problem into account, such as continuity of service etc., the idea of grounding the neutral was abandoned and it was decided that, as far as the system was concerned, the best remedy was the arcing ground suppressor.

Arcing Ground Suppressor

An arcing ground suppressor was installed in our largest generating station and numerous aluminum cell arresters on different parts of the system, believing that they would be the remedy best adapted to meet our requirements.

The arcing ground suppressor has now been in service about five years and the records show that it has operated in every case where a fault to ground occurred, by extinguishing the arc, and preventing an interruption to service.

In addition to preventing service interruptions caused by single-phase grounds, it has the great additional advantage of protecting life. There are at least six cases on record where actual contact with the 13,200-volt wires was made by workmen, which did not result fatally. There is no question but that each of these cases would have been fatal if the suppressor had not been in use. This conclusion is based on experience with the rest of the system not equipped with a ground suppressor, and also on the system before the suppressor was installed.

The arcing ground suppressor consists of three single pole independent motor-operated oil switches, electrically and mechanically interlocked, to prevent more than one operating at the same time. Each switch is connected to ground on one side and to the bus on the other. The suppressor is controlled by a balanced three-phase potential relay, which remains inactive

while the system is balanced, but when unbalanced, due to a ground on one phase, it operates the corresponding phase of the suppressor, which, in turn, grounds the same phase of the bus; thus shunting the current and extinguishing the arc. In cases of short-circuit, an extra precaution is taken to prevent possible operation of the suppressor by the addition of an overload relay which opens the control circuit of the suppressor.

A more detailed account of the arcing ground suppressor, its action and effect on a transmission system, can be found in a paper written by E. E. F. Creighton and J. T. Whittlesey published in the PROCEEDINGS of the A. I. E. E., under date of June 28th, 1912.

Faulty Cable Localizer

Working in conjunction with the suppressor is a device known as the faulty cable localizer, which serves the purpose of indicating the particular feeder on which an arc to ground occurs.

This device consists of a relay connected in series with the neutral of the feeder current transformers. When a ground occurs, the secondary current of the transformers becomes unbalanced, and causes the relay to operate. This in turn, rings a bell and lights a pilot lamp which indicates the faulty feeder. It takes about 0.15 of a second for the localizer and 0.3 of a second for the suppressor to operate.

There is one record of a 15-minute interruption to the service in the Northern Division caused by a cable end bell short-circuiting on an armature lead of a generator in one of our stations, before the suppressor and localizer were installed. Shortly after the suppressor and localizer were put in service, the same thing occurred again and the situation was handled in such a manner that no one outside of the power station was the wiser. A number of instances are on record where a ground has occurred on substation buses without an interruption to service.

Cable Testing

As a further means of reducing our cable troubles to a minimum we made a careful investigation of the possible causes of failure.

For the first few years, all cable was installed by the manufacturer but we finally took over this work ourselves, with the idea of improving the factors entering into cable installation as much as possible.

A thorough study was made as to the best method of making cable joints and particular attention was given to such factors as

1. Favorable weather conditions,
2. Elimination of impurities, air and moisture.
3. Application of insulating varnish between each layer of tape.
4. Careful and even winding of tape.
5. Improving the human element.

Aside from installation precautions, we have made it a practise to inspect cable during the process of manufacture, and to see that our cable specifications are strictly adhered to.

All cables are tested with 26,000-volts for three minutes before putting them in service, but we do not make a practise of testing them periodically. In case there are indications of trouble on a cable while in operation, it is cut out of service, given a test of 26,000 volts for three minutes, and returned to service in case no failure occurs.

In our opinion, a 13,200-volt cable should not be tested at a voltage higher than 26,000, since our experience has shown that too high a testing voltage often weakens the insulation at some point, which weakness finally manifests itself in a complete breakdown, even under normal operating voltage.

High-Potential and High-Frequency Tests

Our line insulators used a number of years ago consisted of many different types, no one type having been standardized. The old insulators not only spilled over during trouble but also became punctured frequently. The insulator creepage surface was then increased and the insulators tested with high-potential 60-cycle current, but without satisfactory results.

About two years ago, we started testing with high-frequency and were soon convinced from the results obtained that the insulators were not capable of standing this test. Various types of insulators were then experimented upon and a design finally adopted having a ratio of puncture to flash-over of about 2 to 1. Now, every insulator before being placed in stock or used on the lines is given a 15-second high-frequency test. Although these insulators are previously tested at 60-cycles, about 2 per cent fail to pass the high-frequency test.

Generator Bus Connection Scheme

Station capacities have increased so rapidly in the last few years that the bus arrangement has become a matter of vital importance in the protection of both apparatus and service.

The ideal arrangement is one that secures the greatest amount of protection to the apparatus, and at the same time localizes and minimizes the effect of trouble.

Two years ago, before beginning work on the new Essex power station, a thorough study was made of various bus schemes and after analyzing those used by the large power plants of this country, it was decided that none of them would be satisfactory. A bus arrangement was then designed which, in our estimation,

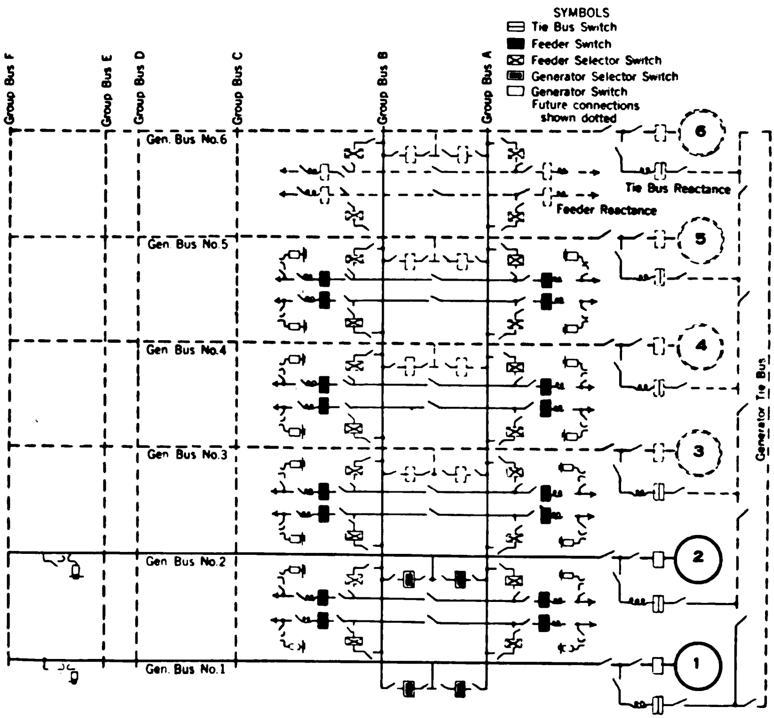


FIG. 2—SELECTIVE BUS SCHEME

would approach the nearest to the ideal, and called the "selective" bus scheme, which is shown in Fig. 2.

The considerations that governed in deciding on this bus layout are as follows:

Flexibility
Simplicity
Limitation of abnormally high currents.
Continuity of service.

The scheme is made for six generators and consists of one loop tie bus, six generator buses, and six feeder group buses of ten feeders each.

This arrangement of connections is a new application of the old arc board scheme and is the most flexible layout known.

By means of the feeder selector oil switches, the feeder oil switches can be connected to one or the other of two given group buses; for instance, the twenty feeders on group buses *A* and *B* can all be connected to group bus *A* or group bus *B* or part to each group by twos.

The maximum flexibility in operation is obtained due to the fact that each generator may be connected directly to any part or parts of the load desired.

The generators are connected to a loop tie bus through tie bus reactances and can be operated in parallel at all times, if desired.

Exciter Connection Scheme

The exciter connections are fully as important as the main a-c. bus connections, inasmuch as the maintenance of the a-c. generator voltage depends upon the reliability of the excitation. In order to secure a dependable excitation service, several sources of supply should be available. The bus should be so arranged that a failure of one source cannot affect the others, except through its effect momentarily on the main bus voltage. The ultimate exciter system that will be adopted in the Essex station is clearly shown in Fig. 3.

Each generator has a direct-connected exciter, three spare exciters and a battery being available for emergency use. Each source of excitation has its individual bus. In case of voltage failure of one of the direct-connected exciters, a low-voltage relay instantly closes the battery breaker, thus connecting the battery to the affected exciter circuit. Immediately after, the breaker of the exciter in trouble opens, due to reverse current. An emergency exciter may then be started up and paralleled with the battery and the battery disconnected and left ready for emergency service again.

A contact-making voltmeter is provided for maintaining the exciter battery voltage automatically at operating value at every instant.

Reactors

Bus Tie Reactors. At the present time, generators of such large capacity are being used that it is necessary to protect them

from the effects of disastrous short circuits by means of internal or external reactance. Where several generators are operated in parallel, it is essential that bus tie or bus section reactors be used

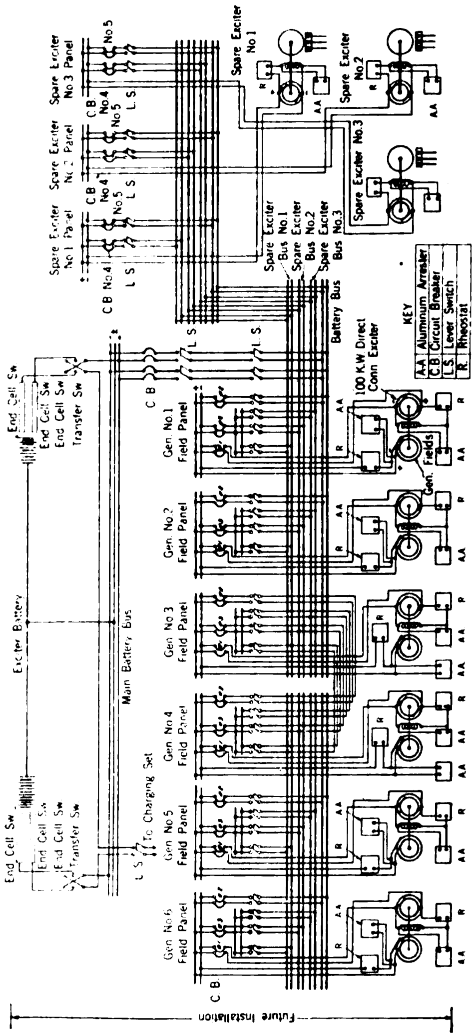


FIG. 3—EXCITER SYSTEM, ESSEX POWER STATION

in order to prevent the combined capacity of all the generators from feeding into any one point of short-circuit. Bus section reactors will limit the current on any one section but take up valuable space in the bus, complicate the connections, and in

cases where parallel feeders are connected to different sections of the bus, it is difficult to obtain balanced currents in these feeders.

In the selection of reactance coils best adapted to meet our requirements, we were governed by the following factors:

Cost
Low losses
Space occupied
Temperature rise
Ability to stand short circuits
Freedom from inflammable material.

The use of tie bus reactors has none of the disadvantages of the bus section reactors, and does limit the amount of short-circuit current on any one section to any value desired, depending upon the amount of reactance used. For this reason, tie bus reactors will be used, connected as shown in Fig. 4.

The curves in this figure show the effect of tie bus reactance on short-circuit currents; assuming that short-circuits occur at the points *G*, *K* and *M*. The per cent tie bus reactance per generator is plotted against the maximum short-circuit current times full load current of generators. Assuming that a short-circuit occurs at points marked *G* or *K* on generator bus No. 3, the maximum short-circuit current flowing into either of these points from the other five generators is shown by curve No. 1. Curve No. 2 shows the total short-circuit current of all six generators. Curve No. 3 shows the maximum short-circuit current of six generators feeding into a point marked *M* on the tie bus. The worst condition, as far as the oil switches are concerned, is to have a short-circuit at either one of the points *G* or *K*. The main generator and tie bus oil switch must open the short-circuit current of five generators when the trouble is at *K*; when at *G* the main generator oil switch is only required to open the short-circuit current of one generator. The slope of the curves is greater for the first few per cent of reactance, and gradually becomes less as the per cent of reactance is increased; a value greater than 10 per cent being impracticable. It therefore follows that a percentage of reactance should be selected which will limit the short-circuit current to a safe value and still not cause the coils to be excessive in size or cost.

Feeder Reactors. Two years ago the generator capacity in our Marion Station had increased to such an extent that the oil switches, in some instances, were unable to rupture the excessive short-circuit current. This unsatisfactory condition com-

pelled us to install reactance coils on all the 60-cycle feeders. Aside from the short-circuit limiting feature of the reactance coils, we believed that a better selective action of relays would result, if reactance coils were installed on both ends of the tie feeders connecting the Marion and City Dock stations.

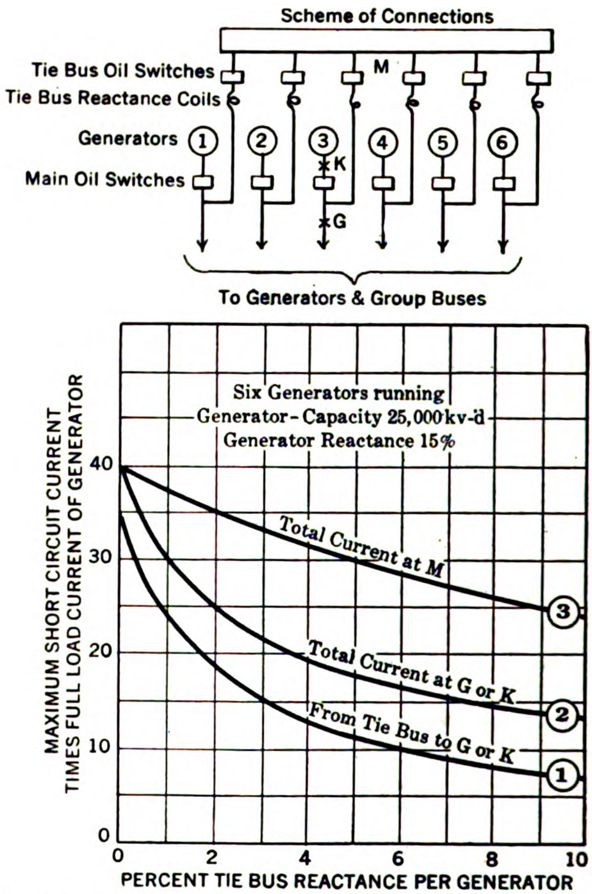


FIG. 4—EFFECT OF TIE BUS REACTANCE SHORT CIRCUIT CURRENT

After studying the conditions then existing, reactors were also installed on the City Dock end of the 60-cycle tie feeders.

Five per cent reactance was chosen as the amount best suited for the radial feeders and two and one-half per cent at each end of the tie feeders. (As a matter of fact, we installed five per cent reactance coils and used the two and one-half per cent taps.)

There were at this time, seven tie feeders between Marion and City Dock and five or six of these operated in parallel at all times. Each feeder consisted of 2.5 miles (4 km.) of cable at the City Dock end, three miles (4.8 km.) of aerial line and one-half mile (0.8 km.) of cable at the Marion end.

If a fault occurred on one feeder there would be 2.5 per cent reactance between either station bus and the fault and an additional 5 per cent reactance between the unaffected tie feeders and the faulty one. As anticipated, this arrangement gave the very best selective action of our relays in case of trouble.

About one year after the installation of the reactance coils, the tabulated records of failures on tie feeders showed that instead of being faults to ground as formerly, they were in most cases, short-circuits. Shortly after this, five sets of aluminum cell arresters were installed 2.5 miles (4 km.) from the City Dock station at the point where the underground cables connected to the aerial lines, with a hope of relieving the local potentials in the cables, but satisfactory results have not been obtained up to the present time.

By a comparison with the 25-cycle system, where no reactors are used on the feeders, it seems evident that the change in the nature of the faults on the 60-cycle system might surely be attributed to some unknown result of the combination of the inductance of the reactor and the distributed capacitance of the cable. To overcome rises of potential at the terminals of the concentrated inductance in the reactors, aluminum arresters were installed on the buses, which, with the arresters already installed on the feeders, placed protection on each side of the reactance. Even with this protection, all the sources of trouble have not been reached, as indicated by the continued failures of cables, and two cases of internal failure of reactors which might properly be attributed to a local rise of voltage internally in the reactor.

It is evident that these troubles are of a deeper nature than would appear on the surface and we are laying plans to make a further study of the surges both from the standpoint of localization of potential and natural frequency.

It seems proper to attribute these troubles to surges. If the troubles were due to weak insulation, they should occur as frequently on the 25-cycle system as on the 60-cycle system, which, as already recorded, is not the case.

Relays

During the early days of the electrical industry more attention was given to the protection of apparatus than to maintenance of service and therefore, the aim of the operating man was to remove the short-circuit as quickly as possible.

In short, the old idea of protection was one of adjusting relays and circuit breakers to protect apparatus against overloads.

Later, with the improvement of station apparatus and its ability to withstand short-circuits, the thought gradually took root that the function of the relay should be primarily to protect against interruption of service to the customer. The result is that the modern idea with reference to relays, is to insure continuity of service. It is only in recent years that this idea has developed and central-station men today do not fear breakdowns in apparatus as much as service interruptions.

Carrying out the idea of service protection, operating companies of late years have gone to considerable expense in electrical features related to the transmission system. The best insurance against interruptions has demanded the use of duplicate feeders over more than one route, such as by means of tie lines, parallel feeders, ring connected feeders, etc. This means a larger and more complicated system, an increase in liability of breakdowns, and therefore a more serious problem as far as relay protection is concerned.

It is obvious, that practically all interruptions in a transmission system will be minimized if faults are easily and quickly removed before they have had time to cause serious trouble.

In order to determine the proper setting of instantaneous overload, inverse time limit and inverse definite time limit relays which are more commonly used on a system of distribution, it is necessary to know the characteristics of the system as well as the characteristics of the generators, automatic apparatus, circuit-breakers, regulators, etc., before anything can be done along these lines, and before the time elements of relays can be adjusted, the following information is necessary:

1. The instantaneous short-circuit value of current through each conductor to which the relays may be applied.

2. The sustained short-circuit value of current through each conductor.

3. The time in changing from 1 to 2.

4. The time required for various automatic circuit-breakers to open the circuit after application of current through the trip coils.

5. The safe current-opening characteristics of various circuit-breakers.

6. The time characteristics of the various relays.

7. The probability and amount of flow of energy in the case of circuits operating in parallel.

If these seven items were known with any degree of accuracy, it would enable one to accurately set relays, but as a matter of fact, it is almost a physical impossibility to arrive at these seven conclusions with any degree of certainty. For instance, the values of short-circuits depend particularly upon the characteristics of the generators and also upon the impedance of the circuit to the point to which the relays are connected. The further the point of the short circuit from the generator, the less will be the difference between instantaneous and sustained short-circuits, or between item 1 and item 2, providing the same apparatus is included between the short-circuit point in question and the generator.

Again, operating companies whose growth extends over a period of years, must necessarily operate generators of different internal characteristics. For this reason, the results obtained from setting a relay for values 1 and 2 for a machine purchased several years ago, will not be the same for a generator installed recently.

Assuming for the moment that the seven items listed are known and an attempt is made to accurately time relays for selective action, the accuracy of current values required to trip a relay can be left as a matter of small concern, for when a short circuit occurs, the current setting of relays is usually exceeded by at least several hundred per cent. This applies equally well to inverse time or definite time relays. It is an impossibility to get selective setting with the inverse time limit relay because it has the unfortunate characteristic of being instantaneous with a heavy overload. This characteristic prevents the use of this type of relay for selective action because a short circuit of sufficient magnitude will cause all the relays from the fault to the source of supply to become instantaneous, and thus any or all of the relays are liable to trip out instead of only the ones nearest the fault.

Better results can be obtained by the use of an inverse definite time limit relay, the time setting of which depends upon the damping action of a permanent magnet on an aluminum disk, giving as great a degree of accuracy as can be obtained in

the calibration of watt-hour meters used in connection with a torque compensator.

This type of relay is more accurate and allows closer setting than any other type, and when once set, remains the same, but in an extensive system, the results obtained from its use are nevertheless disappointing. The reason for this is simple, when it is considered that the time interval between successive circuit-breakers should be equal to the time taken for the circuit-breaker to open its arc, plus a margin of safety to include variation, and if there are several feeder sections in series and the trouble should be near the generating end, the short-circuit may not be cleared for several seconds, which means, of course, a loss of all synchronous load on the system, or in other words, a complete interruption to the service.

From the foregoing, it can be seen that irrespective of the character of the distribution system, it is practically impossible to isolate faulty cables or lines by the relays most commonly used, and therefore the records of most operating companies show that faulty feeders usually interrupt a large area and a great many more consumers than is necessary.

With the relays more commonly used, the most satisfactory results are obtained by using them with a radial distribution system; or, in other words, most operating companies get the best results by adapting their systems to meet the faults in the relay rather than design a relay for a minimum cable outlay.

A well designed transmission system is one which has the following characteristics.

1. Safety in operation for employees and the general public;
2. Suitability of supply for the purpose required;
3. Freedom from interruption.

Therefore, the question resolves itself into one of design, as has been shown.

Failure of supply is usually caused by breakdown of transmission and the primary precaution is therefore careful attention to design, manufacture and maintenance of the various parts of the system, but since no apparatus can be made absolutely immune from breakdown or external damage, the secondary precaution is to make arrangements so that the effects of a breakdown to any part of the system are localized as much as possible.

In some cases, such precautions may mean increased capital cost, but undoubtedly result in a net economy if a broad view is taken.

Fortunately, however, well designed apparatus does not necessarily cost more than badly designed apparatus and it is possible so cheapen the system by closer localization of breakdowns.

Balanced Selective Relay. In connection with the seven tie feeders between City Dock and Marion, mentioned elsewhere in this paper, so much trouble was experienced due to the lack of a selective action of the relays, that a new type of relay known as the "balanced selective relay" was finally installed at each end of these feeders.

The relay coils are connected in series with current transformers of the tie lines. This causes the current in each coil to be proportional to the current in the cable to which it is connected.

Only a single phase of each cable is taken care of by a single relay and there are as many coils on the relay as there are cables. For instance, with seven cables on a three-phase system there are three relays with seven coils per relay.

Each coil on each relay is mechanically balanced against each other coil. The effect of this is that any strong coil can overcome any weak coil. In case a short-circuit occurs on one cable, the current in the faulty cable will of course be greater than the current in any other cable.

Therefore, the coil connected to the current transformer on the faulty cable will have the strongest pull and will close the tripping circuit of this oil switch.

However, if none of the parallel cables are short-circuited, but trouble occurs on some radial cable, the relay will remain balanced and none of the good cables will be erroneously tripped out. The relays operate simultaneously at both ends of a faulty cable and their operation is not affected by fluctuations in voltage due to trouble or change of phase angle between voltage and current. With this particular type of relay, it is necessary to have not less than three feeders in service, in order to secure perfect operation under all conditions. It should be further borne in mind that reactance coils are installed on both ends of the tie feeders in order to secure the best selective action of the relays. It is questionable whether the relays would operate as satisfactorily in all cases without the aid of these coils. The successful operation of these relays is limited to three or more feeders, therefore, they cannot be used on other parts of our system where there are but two parallel cables between stations.

Since the installation of the balanced selective relays, we have

had no case of cable failure on the tie feeders where the relays have not operated properly and there have been more than fifty cases of trouble.

Our operating conditions are such that at times there are but two tie feeders in service, therefore on these occasions it is necessary to disconnect the balanced selective relays and depend on overload protection.

Judging from past experience with different types of relays, a pilot wire relay would seem to be the best one to adopt if it were not for the trouble and expense entailed by the necessity of the pilot wires. Therefore, some scheme based on the pilot wire principle, having all the advantages and none of its disadvantages would be an ideal one for our interconnected system.

Our investigation shows that the nearest substitute for the pilot wire scheme and one that has practically all the advantages is the split conductor principle. During the coming year we expect to make several installations of this character.

Multi-Recorder

The multi-recorder is a device for recording the time to the fraction of a second of the sequence of action of oil switches, circuit breakers, potential indicating devices and aluminum cell arresters. A record of this kind is invaluable to the station man in analyzing troubles or ordinary switching changes.

In order to have complete information on the performance of station apparatus under all conditions, it is highly desirable to have records of the closing and opening of circuit breakers, operation of lightning arresters, appearance and duration of high voltage in the lines and the occurrence of grounds and short-circuits.

At the time of writing this paper the installation of the multi-recorder is not complete, therefore we are unable to give any actual operating experience with this instrument.

Insulation Resistance Recorder

The insulation resistance recorder is an instrument which gives a daily graphic record of the insulation resistance of the system. The results obtained so far from the use of this instrument have been rather disappointing, due to the fact that there are so many old insulators of different insulation characteristics. When the insulators are all changed so that they will have the same characteristics throughout the system, we can, by estab-

lishing a point on the chart which might be called "dangerous," but which is well above the breakdown point, give the operator an opportunity to report when the insulation of the system reaches this value. By isolating the transmission circuits one at a time, the line in question can be removed from the system and later by high potential testing or other methods, the bad insulators can be located and removed from the line.

In using this instrument on lines where the insulators have been standardized, very good results have been obtained. Its use has also shown the need of increasing the insulating qualities of porcelain, which is something that we did not know before.

Air Washer

The capacity of a generator is directly dependent upon its temperature. In order to keep its temperature as low as possible, it must be supplied with a sufficient amount of clean, cool humidified air.

The specific heat of air being low, it is necessary that it be humidified in order to increase its heat carrying qualities sufficiently. It is also necessary that the air be free from impurities in order to prevent a partial or complete closing of the machine ventilating ducts.

A well designed air washer will satisfy all the requirements mentioned above.

Air washers are used in connection with our largest turbo-generators and our experience leads us to believe that their use is almost a necessity; particularly where the conditions are such that the air contains a great many impurities. If an air washer is not used, it is necessary to remove the rotor of a machine periodically and clean the ventilating ducts or in time they will become so clogged with refuse that over heating will result and a burn-out occur.

Where large air blast transformers are used and the air conditions are not satisfactory, it would, in our opinion, be advisable to install an air washer.

Resistance Bulbs and Thermo-Couples

For several years it was our practice to install resistance bulbs in the windings of the largest turbo-generators and synchronous motor-generator sets, in order to know at all times the temperature of these machines. The results obtained by their use so far have not met with expectations.

The resistance bulbs furnished to-day are somewhat more substantial than the earlier type but are still too frail to stand much hard usage. In the windings of our more recent motor-generator sets thermo-couples have been installed which we believe, will give better service than resistance bulbs, as they are less liable to mechanical injury.

The temperature indicator has been found very useful in determining when a machine needs a thorough cleaning. Thus, a possible burnout is prevented which otherwise could not be foretold.

It is our opinion that wherever possible thermo-couples should be installed at the hottest points in the windings of all large generators or motors.

Dampers on Air Blast Transformers

In most of our stations where air-blast transformers are installed a common air chamber is utilized for all the transformers and we have found this method of air supply more economical than to use a separate and independent blower for each transformer. Each transformer is equipped with a top and bottom air damper so that in case of fire in the transformer, the dampers may be closed, thus shutting off the air supply and smothering the fire.

We strongly recommend top and bottom dampers on all air-blast transformers especially where a common air chamber is used. If the transformers are not equipped with both top and bottom dampers and a fire starts in one of the transformers, it is necessary to cut off the entire air supply for a considerable time depending upon how long it takes to put out the fire. This might compel the station man to disconnect the other transformers from the service; thus resulting in a complete interruption.

Coherer Alarm Device

This device is used to register predetermined voltage rises on the transmission line itself, across reactance coils or on aluminum cell lightning arresters. In order to get a permanent record of its action, it can be connected to a relay which will make a record on a multi-recorder. This device has been found very convenient to register the discharges of our aluminum cell lightning arresters.

Previous to the installation of this device, it had been the custom to install with each aluminum cell arrester a discharge

recorder which has a continuously moving paper punctured by the discharges. We finally came to the conclusion that while these recorders gave us much desired information, the continual replacement of paper record rolls was expensive and troublesome.

Potential Indicating Devices

Electrostatic potential indicating devices are used to indicate potential on feeder circuits. The instrument is connected to the middle point of two strain insulators in series, which are connected between each live wire and the ground. The displacement current through the insulators is sufficient to operate the instrument.

Another method of obtaining the voltage indications is to install potential transformers whose secondaries are connected to indicating lamps or voltmeters. However, this means is rather expensive and the required space for potential transformers is not always available.

It would therefore seem that the potential indicating device now on the market might fill a long felt want.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

REPORT OF THE TRANSMISSION COMMITTEE

I—DATA FROM OPERATING PLANTS ON THE EFFECT OF ALTITUDE ON THE OPERATING TEMPERATURE RISE OF ELECTRICAL APPARATUS

BY PERCY H. THOMAS, CHAIRMAN

RECOGNIZING the absence of conclusive data on the altitude correction to be applied to the temperature rise of electrical apparatus, and further the lack of uniformity of the general practise as well as the frequent entire omission of the correction, the Transmission Committee undertook the collection of data as to the opinion and practise of operating engineers and sent a list of questions to 150 companies and individuals.

The information received is herein summarized and discussed. It should be noted that no effort has been made by the Committee to make laboratory tests or scientific investigations—nor does the Transmission Committee offer any definite rule of correction, for this is the function of the Standards Committee. The data collected is presented as information for the use of any committee or individuals who may find it helpful.

Thirty-one replies were received. Of these 15 were from plants operating apparatus at 5000 ft. (1524 m.) altitude or higher, which are here called high-altitude plants. Of these 15 high altitude plants six make no correction for altitude and six have noticed no effect of altitude. Comments of more or less interest have been received from some of the above and are here summarized.

From W. N. Clark, Arkansas Valley Ry. Lt. and Pr. Co., Canon City, Colorado.

Altitude 9000 to 10,000 ft. (2743 to 3048 m.)

Take account of altitude both in purchasing and loading transformers. Have no definite rule for correction but have by experience determined which design of transformers operate satisfactorily. The transformers in question are step-down transformers in the Cripple Creek district, ranging in capacity from 100 to 900 kw.

We have noted that on some of the more modern closely rated equipment that the temperature remains high. This does not apply to some of the older more liberally rated apparatus such as generators and transformers.

Six 200 kv-a., oil-insulated, self-cooled transformers required water cooling coils to prevent constant excess temperature at rated capacity, however, part of the cause was poor circulation of air in and out of building.

The correction factor is not large. I think it should be made. I think the capacity should be rated lower for the higher altitudes something similar to the method of rating air compressors.

Lightning discharges take place over longer setting of horn-gap arresters.

From W. O. Vickery, The Trinidad Electric Transmission. Railway and Gas Co., Trinidad, Colo.

Altitude 6000 to 7000 ft. (1828 to 2133 m.)

No account taken of altitude up till spring of 1915.

No rules adopted, but it is thought best in future to specify temperature and altitude in purchasing electrical apparatus.

From general observations it is noted that oil-insulated, self cooled transformers run approximately 10 per cent higher than manufacturer's guarantee. This is also noted on induction motors, except that induction motors run only about 7 per cent higher than guarantees. Generators seem to operate about 5 to 6 per cent higher than guaranteed rating of temperature.

Nothing definite. However, the loss of the coils in a 2000 kw. turbo-armature we believe could be partly attributed to higher temperature resulting from high altitude.

Generally speaking, increased temperature at high altitudes was called to our attention in the spring of 1915. Since that time, observations have been made, which lead us to believe that there is considerable increase in temperatures of electrical apparatus when operating at altitudes of 7000 to 10,000 ft. (2133 to 3048 m.) above sea level, and it is believed rules should be formulated covering such apparatus when making purchases.

From R. W. Toel, Chf. Engr., Denver Tramway Co., Denver, Colo.

Altitude 5280 ft. (1609 m.)

Take account of altitude in loading transformers.

Air transformers have been noticed to operate from 10 to 12 deg. cent. higher than manufacturers specifications under given load conditions.

Air transformers have failed due to high temperatures operating under normal conditions.

Should think that a correction factor should be made of at least 10 deg. cent. higher than temperature rating for apparatus used at sea level under same operating conditions.

From J. H. Rider, 8 Queen Anne's Gate, Westminster, S. W. London.

Altitude 6000 ft. (1828 m.), neighborhood of Johannesburg, So. Africa.

Takes account of altitude in generators, motors and transformers both in purchasing and loading apparatus.

To secure a maximum temperature rise of 35 deg. cent. in motors with an ambient air temperature of 35 deg. cent., motors must not exceed a temperature rise of 30 deg. cent. with an ambient air temperature of 25 deg. cent.

The neighborhood of Johannesburg is at an altitude of 6000 feet above sea level, and from experience where I have had to adopt the following basis for the temperature of the motors, namely, a maximum temperature rise of 35 deg. cent. with the surrounding air at a temperature of 35 deg. cent.

As the plant has to be tested at the maker's works at sea level, the prescribed limits for such a test are a temperature rise of 30 deg. cent. with the surrounding air at a temperature of 25 deg. cent. as experience has shown that these figures correspond very closely indeed with the limits for the higher altitudes.

I have had considerable difficulty with some manufacturers in getting them to design their plant for what appears to them to be abnormally low temperature rises at sea level, but by persistence have succeeded now in getting those figures without difficulty.

Yes; correction should be made for altitude.

From K. C. Randall, 133 *Dewey Avenue, Edgewood Park, Pa.*

Have never allowed nor encountered requests for allowance in rating of apparatus because of expected operation at high elevations.

Have never heard of instances where loading is in any way controlled by elevation.

I believe that in general the extra complications from introducing corrections for elevation will be largely a paper burden and in general of no material significance, particularly as standard apparatus should be employed as far as possible and that any acknowledgment of the effect of elevation will only add to the expense of both consumer and manufacturer without any return to either. This is particularly true, as the wide range of conditions of installation, ventilation and operation will have in general much more bearing on operating conditions than variation in elevation.

From Charles S. Ruffner, Genl. Mgr., The Electric Company of Missouri, Webster Grove, Mo.

Confining the questions strictly to the effect of air pressure on thermal conditions might omit considering other factors in the cooling of apparatus at high altitudes. The prevailing lower temperatures at high altitudes, with particular reference to the invariably cool nights, might, in practise entirely offset any difficulty with the volumetric thermal capacity of the air.

Personally I have not noted any cooling difficulties in any apparatus operated at high altitudes arising from the rare atmospheres, and I cannot think of any important practical question in that connection excepting only in the design of forced ventilating systems. In that case, the

apparatus being cooled by air blast might require a larger volume of free air. Such a case has not, however, come under my observation.

A few simple experiments on the rate of transfer of heat from any substance to atmosphere of different pressure might determine the quantity of air at different pressures required for equivalent cooling effects.

From P. M. Downing, Chf. Engr., Hydroelectric Dept., Pacific Gas and Elec. Co., San Francisco, Cal.

In this connection I might say that the effect of altitude on the temperature reading of electrical apparatus, is something that we have never considered of great importance. The writer has had personal experience in the operation of such apparatus at altitudes ranging from sea level to 8500 ft. (2590 m.), and although I have never made any careful tests, have never been able by casual observation to notice any change in the heating of the apparatus.

From C. D. Gray, Asst. Elec. Engr., J. G. White Engineering Corporation, 43 Exchange Place, New York.

Our personal opinion is that if the altitude is over 6000 or 8000 ft. (1828 or 2438 m.) some attention should be given to this matter and we would probably specify about 5 deg. lower temperature than for a machine used at lower altitudes.

From J. F. Dostal, Genl. Mgr., The Colorado Springs Light, Heat and Power Co.

Altitude 6000 and 7000 ft. (1828 and 2133 m.)

Take no account of altitude either in purchasing or loading apparatus.

Feel that some allowance should be made. Have noticed that fans run hot.

From E. R. Davis, Genl. Mgr., Pacific Light and Power Corporation, Los Angeles, Cal.

Altitude 5000 ft. (1524 m.)

To yours of July 26th covering data sheet for references to effect of altitude in temperature of electrical apparatus, the replies to all the questions except the first may be summed up in the statement that this company is not taking any account of the effect of altitude on operating apparatus and has no observations or tests on record which would have any bearing on the matter.

The above data indicate clearly that most engineers operating at altitudes over 5000 ft. (1524 m.) have ignored the question of the effect of altitude on the operating temperature of electrical apparatus. This appears rather to be because of lack of tests on their own apparatus and lack of convincing engineering data in any form. As at most, the effect of altitude involves a limitation of only a few per cent and as apparatus is seldom loaded to exactly 100 per cent of capacity, the point of view is natural. However, at the higher altitudes where engineers have made an

effort to look into the subject they usually conclude that a correction should be made.

While in most cases the altitude correction is not important, there are some where it is of great importance, for example to such a company as the Chile Exploration Company which expects to have 100,000 kw. of transformers and motors at 9000 ft. (2743 m.) altitude, much of which will be carefully rated, or as the Cerro de Pasco Mining Co. with apparatus at the extreme altitude of 14,000 ft. (4267 m.)

Obviously the data collected by the committee form no basis for the drawing of a definite altitude correction, and the collection of data was not undertaken with that in view. It serves however to show the attitude of engineers in general on this question and thus it is of considerable interest.

Two of the replies above quoted are to the effect that their authors considered that the altitude correction is not of magnitude enough or sufficiently precise to warrant a formal rule.

Two of the replies included certain matters not strictly pertinent to the subject of the inquiry but still cognate and of some interest, they are appended below.

From J. H. Rider, 8 *Queen Anne's Gate, Westminster, S. W., London.*

One of the things which no manufacturer ever pays attention to is that the temperature rises of generators and motors tend to increase as time goes on, even with the same load. This is because the first temperature tests are made with the machine in a new and clean condition, with all ventilating passages in good order. During working, however, it is impossible to keep dirt from collecting in the air passages, and so the ventilating facilities get worse and worse as time goes on.

It is quite impracticable to clean out the ventilating spaces without dismantling and then rebuilding the whole machine, which, in practise, is impossible, as a user is entitled to expect his machine to run satisfactorily for very many years, if he gives proper attention to the bearings, brushes, etc.

The above point, perhaps, does not concern only motors which are intended to work at high altitudes, but it shows that the test temperature of such machines at sea level must be quite as low as those which I fixed upon if satisfactory after running is to be obtained.

If your committee, therefore, could both fix upon a standard for temperature tests at sea level to give reasonable working temperatures at high altitudes, and also make such sea level figures low enough to provide for the gradual clogging of the air passages, you will have done a very great work.

From R. S. Masson, 705 *Security Building, Los Angeles, Cal.*

I was much interested in your letter about the effect of altitude on the temperature rate of electrical apparatus. I have been determining for

a number of years in my own mind that humidity was the real nigger in this altitude woodpile. In other words, I am of the opinion that altitude as such does not effect the cooling capacity of the air to any material extent but that humidity, which may be directly related to altitude in some instances, causes the trouble.

When the writer undertook to operate certain motor-generator sets in Phoenix, Arizona, about three weeks ago, it was found that the machines ran very much above their testing temperature and, after accusing power factor and other common enemies, it was found that there must be another cause. Phoenix was then a close neighbor to great areas of desert and the average humidity was so low that the air was practically dry. We then tackled this problem of constructing a humidor which, in effect, was not much different from any of the attempts which have been made by power house operators; ours having the form of water screens rising out of a water bath like the old overshot water wheel and the air flowing through these screens. This air was conducted through canvas housings to the ends of the motor generator sets and allowed to flow out through the stators, without changing the machines themselves at all. The effect was very marked and increased the capacity of the normal rated 600-kw. machines about 125 to 150 kw. at the same temperature rise.

Referring then to the problem as presented in your letter. Here was a machine located at an elevation of about 800 ft. (243 m.) which was having all of the troubles that had previously been experienced at altitudes of 8000 and 10,000 ft. (2438 to 3048 m.) It would be interesting to have some of the operators of plants in high altitudes test out this method of cooling the air to see if they cannot put their machines on the same basis as the sea level machines.

This test which we made, however, was not quite true, as the effect of blowing the air through these water screens was to actually cool the air by evaporating the water and, of course, the machine was practically running in a lower temperature. In order to make a true test of the effect of humidity alone it would be necessary to re-heat the air, after it has accumulated moisture, to the temperature of ordinary air. This test I will be glad to make, if it would be of any interest, as it can be done in the said Phoenix motor-generator apparatus without inconvenience or unnecessary delay.

The above extracts are self explanatory.

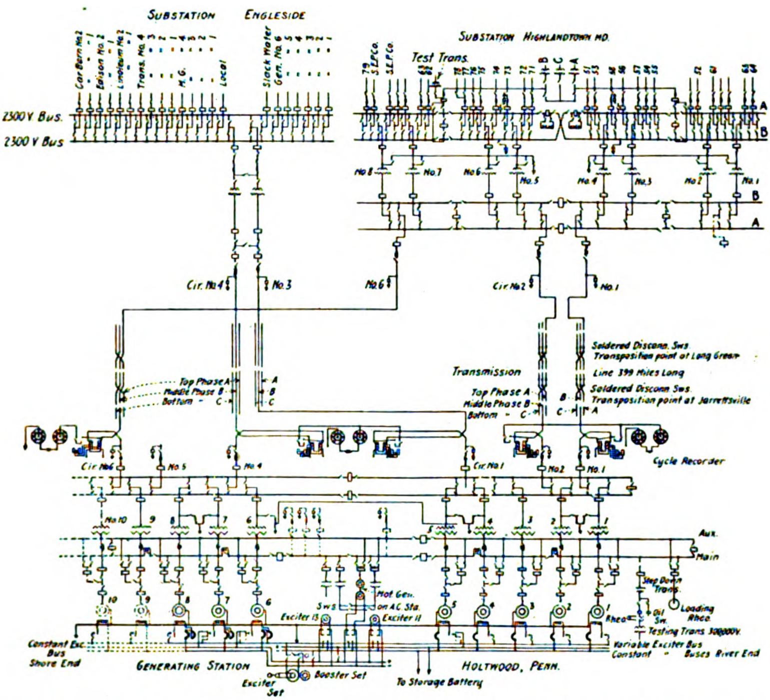
II—EXPERIENCE WITH GROUNDED NEUTRAL ON HIGH-TENSION TRANSMISSION LINES

To secure a comparison of the experiences of various companies operating high tension systems with grounded neutrals, the Transmission Committee sent an information blank to a large number of power companies and the present report covers the information secured.

It is believed that the various replies can be best offered by printing verbatim or in rearranged form the more important reports; comments will then be made.

From the Pennsylvania Water and Power Company,
Mr. A. Bang, Testing Engineer.

The Pennsylvania Water and Power Company operates a hydroelectric plant located at Holtwood, Pa. The generating capacity of this plant is at present about 83,500 kw.; the current is three-phase current, 25 cycles, and generated at 11,000 volts. This voltage is stepped up to 70,000 volts by means of three-phase transformers which are delta connected on the low-tension side and star connected on the high-tension side.



ONE LINE WIRING DIAGRAM OF GENERATING STATION—TRANSMISSION AND SUBSTATION

The bulk of this power is transmitted to Baltimore, Maryland, through three 70,000-volt 40-mile (64-km.) long transmission circuits. At the terminal station in Baltimore the voltage is stepped down from 60,000 volts to 13,200 volts by means of three-phase transformers, delta connected on the high-tension side and star connected on the low-tension side. This power is then distributed through a 13,000-volt underground cable system to a number of substations located in Baltimore.

A minor part of the power generated at Holtwood is transmitted at 70,000 volts to Lancaster, Pa., where the voltage is stepped down to 2200 volts through single phase transformers connected in open delta.

The accompanying one line wiring diagram and tabulations of the resistances and reactances of the various apparatus used in the generation and transmission of power will give an idea of the size and characteristics of the plant and transmission system.*

The transmission of power to Baltimore was started in the autumn of 1910 and to Lancaster in the autumn of 1913.

Both of these systems are run with the neutral grounded at the power house only. The Lancaster system has always been run grounded; the Baltimore system has been grounded all the time except for a short interval during the summer of 1911 when the grounds were temporarily disconnected to try out such method of operation.

Ungrounded connections did not seem to give any relief from lightning disturbances experienced during that summer and it was felt that when run ungrounded the possibility of the line being kept in service for any length of time, with one phase accidentally grounded and without the location and the character of the ground being known, there would be incurred danger to life and property along the transmission line and especially would nearby telephone service be exposed to damage. As in the case of *short circuits* on the transmission line, a very brief interval of arcing may suffice to cause great damage to conductors and insulators on account of the large generating capacity back of the trouble, and as the majority of the transmission line trouble has been short circuits and not single grounds, it has been thought better not to make any difference between these two cases, but to try to cut out the circuit immediately upon its becoming faulty and carry the voltage on a duplicate circuit, independent of whether the cause of the trouble was a short circuit or a single phase ground. It has been endeavored to arrange the relay apparatus so as to cut down as far as possible the number of seconds that a faulty line may be exposed to short circuits.

The Baltimore system, where there are three transmission lines, is normally operated so that certain groups of transformers are connected to each line in such a way that the high-voltage sides of the lines are entirely independent, while the low-tension sides of the transformers are all connected to the same bus; though to some extent separated by reactance coils.

For this system two transformers per circuit are grounded during the lightning season, whenever possible. The object of this arrangement is to obtain a heavier rush of current on that transmission line on which the spill-over occurs so as to operate special series relays used in connection with the Nicholson arc extinguisher which is installed on these lines. Tests indicate that there is no harmful interchange of current when the neutrals of two transformers in parallel are grounded, even when these transformers are of different capacity or made by different manufacturers.

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*For further descriptive details of this plant and particularly the transmission lines see: (1) Engineering Data Relating to High Tension Transmission Systems, Sub-committee Report. A. I. E. E. PROCEEDINGS, October 1914. (2) Foundations for Transmission Line Towers and Erection of Towers, by J. A. Walls, A. I. E. E. PROCEEDINGS, June 1915. (3) Four Year's Operating Experience on a High Tension Transmission Line by A. Bang, A. I. E. E. PROCEEDINGS, July 1915.

Outside of the lightning season only one transformer per circuit is grounded as a matter of switching convenience.

On the Lancaster system only one transformer is normally used and consequently only one grounded.

At present the transformers are grounded through metallic resistances. The system was originally run dead grounded from the neutral point of one transformer per circuit. It was thought that the ground short-circuit currents produced thereby were too heavy, and that some of the early transformer breakdowns might have been due to this cause, so a resistance was inserted between transformer and neutral ground. From tests and calculations made later it would appear that even with the present reactance coils the current that one single dead grounded transformer can receive may be dangerous but that this would not be the case if several transformers of the same bank were grounded at the same time and that with all the transformers grounded at the same time, it would be quite possible to run safely without ground resistance. However, this latter arrangement has not yet been tried out as a practical operating condition on the high-tension transmission lines.

On the 13,000-volt cable system in Baltimore the arrangement of having all the transformers dead grounded has been adopted and been in service for the last year and a half apparently without causing any inconvenience. The reason why this system was adopted here instead of the former system where only one transformer was grounded through a resistance was to make certain of a sufficient current on a ground to trip the relays which on account of the desire to get selective action of the relays between various substations, are set for rather high tripping current. The condition of running entirely ungrounded on the cable system has never been tried but would hardly be of any great benefit, as most of the cable troubles apparently start between conductors and not as grounds.

The first resistance tried for the transformers at the power house were concrete blocks, which proved unreliable on account of lack of constancy in resistance and because they gave rise to arcing when voltage was built up on them.

Cast iron grid resistances were then substituted and have been satisfactory on the whole. The difficulties experienced with them are their limited heat capacity in the case of some ground hanging on unexpectedly long, and also on account of the occasional failure of the insulation between grids.

The ground connections used at the Holtwood power house are of different types. In the main they consist of:

(a) Several copper plates buried in the mud in the forebay.

(b) Twenty-four $1\frac{1}{2}$-in. (38-mm.) galvanized iron pipes driven 9 ft. (2.7 m.) in the wet earth in the neighborhood of the first tower of the transmission line.

(c) Several heavy castings lowered in the tail race (the connections to some of these latter were accidentally torn loose and have not been restored.

(d) Besides the above artificial grounds an effort has been made to tie in all metal parts in the power house with the ground system and to tie in specially with such metal parts as are in direct connection with the river water, as for example, head gates and racks. The power house

grounds are furthermore tied in with the overhead ground wires on the transmission lines. All these connections are made solid and, therefore, do not easily lend themselves to regular tests; such tests are consequently not made, but occasionally inspections are made of the cables connecting with the ground plates, etc., to see that such connections have not been torn loose.

From time to time other tests have been made on the individual "ground" and some of the results are as follows:

1. Forebay ground consisting of four interconnected copper plates, 2 ft. 6 in. (82.2 cm.) by 3/32 in. (2.38 mm.), buried in the mud, 0.04 ohms.

2. Large castings in the tail race (three in multiple) 4.4 ohms.

(3) Individual tower grounds on the transmission line, stubs set in concrete but grounded by means of a paragon cone and measurements taken with the ground wire removed, 150 to 350 ohms.

(4) Recent measurements taken between all the power house grounds connected in multiple, and a similar system of grounds at the substation 40 miles (64.3 km.) away, showed a combined resistance of about 2 ohms, though it is not possible to say how much of this is located at the power house and how much at the substation.

The current in the neutral is used to secure selective relay operation in the following way:

One or two of the transformers of each group supplying a transmission circuit have their neutrals grounded at the power house. The ground current from any transmission circuit will, therefore, pass through the neutral ground resistance of that circuit, and this ground current acts through a current transformer on a relay, which latter opens the low-tension switches of the transformers connected at the power house to that particular transmission circuit. This system, from the very start of the plant, has given satisfaction in respect to selective action on grounds and is considered as one of the main advantages of running the system with a grounded neutral. It is to be noted that the above relay action is quite distinct from the action obtained with the Nicholson arc extinguisher, the latter requiring a heavy ground current to energize its series relay, while the former does not require heavy current for the operation of its relay.

The current obtained when an accidental ground takes place on the line will naturally vary greatly, depending upon

(a) The character of the ground, *i. e.*, whether it in itself contains appreciable ohmic resistance or not; but even if we consider that we are dealing only with "dead grounds" the amount of current will vary with the total amount of impedance in the circuit and will, therefore, depend on

(b) The amount of resistance contained in the grid iron rheostat used in the neutral of the transformer;

(c) The number of transformers grounded;

(d) The generator capacity behind the ground;

(e) The location of the ground, *i. e.*, whether near the substation or power house;

(f) Furthermore the ground current will vary with time, being greater during the first few cycles and then gradually dying out, due to the de-

magnetizing of the generators and the heating of resistance grids, in the neutral.

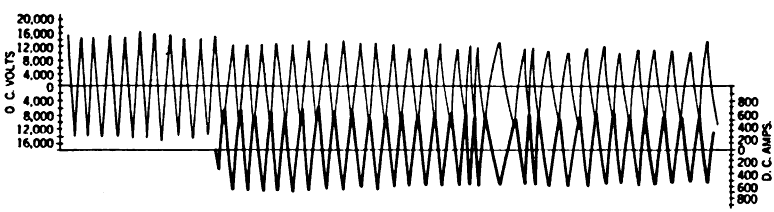
In the following tabulation some results are given of calculations of the ground current as based on a number of oscillograms taken on the P. W. & P. Co's. system to determine the exact value of ground currents for different locations and conditions.

INITIAL RUSH OF CURRENT WHICH TAKES PLACE ON THE P. W. & P. CO'S. SYSTEM WHEN A LINE IS GROUNDED.

BALTIMORE—HOLTWOOD CIRCUIT

Number of generators used	Number of transformers grounded	Location of ground	Initial ground current	Ohmic res. in neutral rheo. per transformer
3	2	At power house	656 amp.	58.4ohms
		At sub-station	430 "	58.4 "
3	1	At power-house	380 "	58.4 "
		At sub-station	290 "	58.4 "
HOLTWOOD—LANCASTER LINE				
1	1	At power house	280 amp.	116 ohms

The accompanying sample oscillogram illustrates the characteristics of such a ground current.



"B" PHASE GROUND IN PINEY ISLAND—GEN 1 AND 2—TRANS. 1 AND 2 —GROUND STACKS 1 AND 2—VOLTAGE 10,500 VOLTS BEFORE TEST

The operating record for 1915 of the P. W. & P. Co's. system is given below, as far as single grounds are concerned without accompanying short circuits. It should be noted that in *all* cases the grounds were cleared without serious interference with the operation of the system and that none of them lasted more than four seconds. (Only in one case was a small part of the load lost and then only for a few minutes.)

NUMBER OF SINGLE WIRE GROUNDS ON THE HOLTWOOD-BALTIMORE CIRCUITS, 1915, THEIR CAUSES AND THE METHODS BY WHICH THEY WERE CLEARED.

	Cleared of itself without relay action	Cleared by arc extinguisher	Cleared by interlocking relay	Cleared by hand	Total
Lightning	1	4	1	0	6
Sleet	0	0	0	0	0
Birds	..	..	6	..	6
Insulator failure	0	0	0	0	0
Total	1	4	7	0	12

Grounded operation is preferred as enabling a faulty line to be cut out of service promptly so as to minimize damage to equipment or damage to property or life of outsiders, specially since a short period of operation ungrounded did not prove of benefit in reducing disturbances from lightnings pillovers. An advantage claimed for an ungrounded system is that it permits service to be continued in the event of failure of insulator on one conductor, but it is rare to have a sufficient number of suspension units on one insulator on a steel tower line damaged simultaneously to an extent to cause a permanent ground at that insulator, so that, as far as the circuits of the Pennsylvania Water and Power Company go, the advantage above claimed is of slight importance. The grounding of the neutrals should under certain conditions, result in subjecting the insulation of the high-tension circuit to a stress lower than that obtaining when running ungrounded. However, since the effort has been made on this company's lines to insulate rather against lightning than against generator voltage (insulation for 110,000 volts working pressure being in use on a circuit having a working voltage of but 70,000 volts) such lower stressing of the insulators has not been considered a factor of importance.

In short, grounded neutral operation facilitates certain protective relay operation, while the benefits to be derived from ungrounded operation in the sense of obtaining freedom from trouble from momentary flashovers on a transmission line, or being able to operate for a length of time with one conductor grounded, have not appeared worth while in practise.

The grounding of the neutral at the power house only, does not seem to influence telephone operation at all during normal operation. Whenever a ground occurs on the transmission line and the current therefore is flowing back through the soil to the station, very serious interference with telephone conversations will be observed, but this condition will as mentioned ordinarily not last for more than a few seconds.

Outside the lightning season, both high-tension grounds and short-circuits are cleared by overload relays and ground relays at the power house, and reverse current relays at the substation. During the lightning season the Nicholson arc extinguisher equipment is put in service and given the first chance to extinguish flashovers on the line. In case this apparatus and the relay arrangement described both fail to clear the trouble, the field is destroyed automatically on all the generators at the power house and brought back again after 1.5 seconds.

As to the chief causes of interruptions an idea will be had from the tabulation below, which gives a record for the year 1915 of all the disturbances on the Pennsylvania Water and Power Company's system as far as they had their origin on one of the three Baltimore circuits. This record includes both grounds and short circuits. The disturbances are divided into three groups, depending on the momentary loss of load resulting from them, *i. e.*, total interruption (T. I.), partial interruption (P. I.), and mere voltage or frequency disturbances (V. D.).

Operating record for the Holtwood-Baltimore transmission line:

Cause	T. I.	P. I.	V. D.	Total
Lightning	3	13	8	24
Defective insulators	..	1	..	1
Sleet on cables	..	..	2	2
Birds on line	..	..	8	8
Wires blown together	..	1	..	1
Defective cable clamp	1	..	..	1
Lineman's mistake	..	1	..	1

Only a current less than one ampere flows normally in the neutral connection. The frequency of this current is not known.

AVERAGE REACTANCE AND RESISTANCE OF BUS REACTANCE COILS AND UNDERGROUND CABLES USED IN SHORT CIRCUIT CALCULATIONS

HOLTWOOD BUS REACTANCE COILS

	70,000 volt values		13,200 volt values	
	Reactance	Resistance	Reactance	Resistance
1 bus reactance coil	21.5 ohm	.352 ohm	1.037 ohm	.017 ohm

HIGHLANDTOWN BUS REACTANCE COILS.

	70,000 volt values		13,200 volt values	
	Reactance	Resistance	Reactance	Resistance
1 bus reactance coil	30.8 ohm	.381 ohm	1.49 ohm	.0184 ohm

HOLTWOOD-BALTIMORE—TRANSMISSION LINES

	70,000 volt values		13,200 volt values	
	Reactance	Resistance	Reactance	Resistance
1 transmission line	13.1 ohm	12.1 ohm	6330 ohm	.5850 ohm

INDIVIDUAL REACTANCE AND RESISTANCE OF TRANSFORMERS

Holtwood Transformers

Operating No.	Office number	Serial number	Kw. rating	Per cent impedance	Per cent reactance	Per cent resistance (at 50°C)	Reactance in ohms phase H. T. (at 25 cycl.)	Resistance in ohms phase H. T. (at 50° C.)
1	102.	598555.	7,500	4.03	3.82	1.25	25.0	8.20
2	103.	598554.	7,500	5.14	5.00	1.20	32.7	7.83
3	108.	298572.	10,000	4.98	4.90	.99	24.0	4.85
4	109.	301699.	10,000	4.98	4.90	.99	24.0	4.85
5	107.	278098.	10,000	4.98	4.90	.99	24.0	4.85
6	105.	750832.	10,000	4.90	4.84	.84	23.7	4.12
7	106.	750833.	10,000	3.57	3.52	.72	17.3	3.52
8	110.	343227.	10,000	4.98	4.90	.99	24.0	4.85
9	111.	1198081	12,500	5.08	5.03	.77	19.6	3.02
10	....	....	....	....	....	....	....	......
Highlandtown Substation Transformers.								
2	207.	360644	12,500	5.32	5.23	.95	15.1	2.74
3	201.	237663	10,000	4.94	4.79	1.21	17.2	4.33
4	202.	237664.	10,000	4.94	4.79	1.21	17.2	4.33
5	203.	237662.	10,000	4.94	4.79	1.21	17.2	4.33
6	204	237661.	10,000	4.94	4.79	1.21	17.2	4.33
7	205.	278093.	10,000	5.05	4.90	1.22	17.6	4.41
8	206.	324822.	10,000	5.05	4.90	1.22	17.6	4.41

REACTANCE AND RESISTANCE OF GENERATORS AND REACTANCE COILS AT HOLTWOOD

Holtwood Generators

Number	Kw.-rating	Reactance (at 25 cycles) Starting value L. T.	Starting value H. T.	Final value L. T.	Final value H. T.	Resistance at (50°C.) L. T.	Resistance at (50°C.) H. T.	Field current amps.	Averages H. T. reactance Start	Averages H. T. reactance Final	Averages H.T. resistance
1	10,000	1.32 Ω	53.4 Ω	5.67 Ω	229 Ω	.0651 Ω	2.63 Ω	275			
2	10,000	1.32 "	53.4 "	5.67 "	229 "	.0651 "	2.63 "	275			
3	7,500	1.21 "	48.9 "	5.67 "	229 "	.1075 "	4.35 "	275			
4	10,000	.84 "	33.9 "	4.53 "	183 "	.0649 "	2.62 "	275			
5	10,000	.84 "	33.9 "	4.53 "	183 "	.0649 "	2.62 "	275			
6	12,000	1.48 "	59.8 "	4.78 "	193 "	.0651 "	2.63 "	300			
7	12,000	1.48 "	59.8 "	4.78 "	193 "	.0585 "	2.36 "	300			
8	12,000	1.29 "	52.3 "	5.60 "	227 "	.0675 "	2.72 "	450	49.4	208	2.82

Holtwood Reactance Coils

1	.670 Ω	27.1 Ω	.01479 Ω	.598 Ω		
2	.520 "	21.0 "	.01082 "	.437 "		
3	.520 "	21.0 "	.01082 "	.437 "		
4	.520 "	21.0 "	.01082 "	.437 "		
5	.525 "	21.2 "	.01432 "	.579 "		
6	.580 "	23.5 "	.01582 "	.640 "		
7	.833 "	33.7 "	.01495 "	.604 "		
8	.580 "	23.5 "	.01495 "	.604 "		
9	.465 "	18.8 "	.01405 "	.570 "	2.34	.545

From Public Service Electric Company,
Mr. N. A. Carle, Chief Engineer.

We distribute current at 13,200 volts, three-phase, 60 cycles, with the neutral not grounded. Several years ago, we contemplated grounding the neutral but decided at that time to install an arcing ground suppressor on the system. Since the arcing ground suppressor has been installed we have found that whenever a ground occurred, the surge suppressor would immediately make a dead ground on the phase that was in trouble and this would give the operator time to parallel another line or cable to take the bad one out of service.

The surge suppressor has never failed to operate in case the system became grounded on any one phase, and has, in several instances, in addition to protecting the system, saved employees from becoming electrocuted when they came in contact with the 13,200-volt wires.

We have found in many instances, that a line insulator may arc over, causing an instantaneous ground which is instantly stopped by the arcing ground suppressor cutting in. After taking out the suppressor and testing the line, we found in these cases that the ground had disappeared.

If a ground occurs on a 13,200-volt line paralleling a neighboring telephone wire, it causes a very slight disturbance, the extent of which depends upon the length of the paralleling circuits; the amount of current flowing, etc. In case a short-circuit and ground occurs at the same time, the ground suppressor going in would cause very serious telephone disturbances, depending upon the length of the paralleling circuits. In order to remedy any trouble that might arise from this source, we installed in the operating station in which the ground suppressor is installed, instantaneous circuit opening relays on each generator, so that in case a short circuit occurs on any feeder, the arcing ground suppressor cannot operate.

In my opinion it does not pay to ground the neutral of a transmission system unless the voltage is moderately high, say for aerial systems above 60,000 volts, and for cable systems, above 22,000-volts. It is not so very difficult to insulate cables for 22,000 volts, and it is not particularly hard to get line insulation that will stand up satisfactorily under 60,000 volts. The highest voltage under which we are operating at the present time is 13,200 volts.

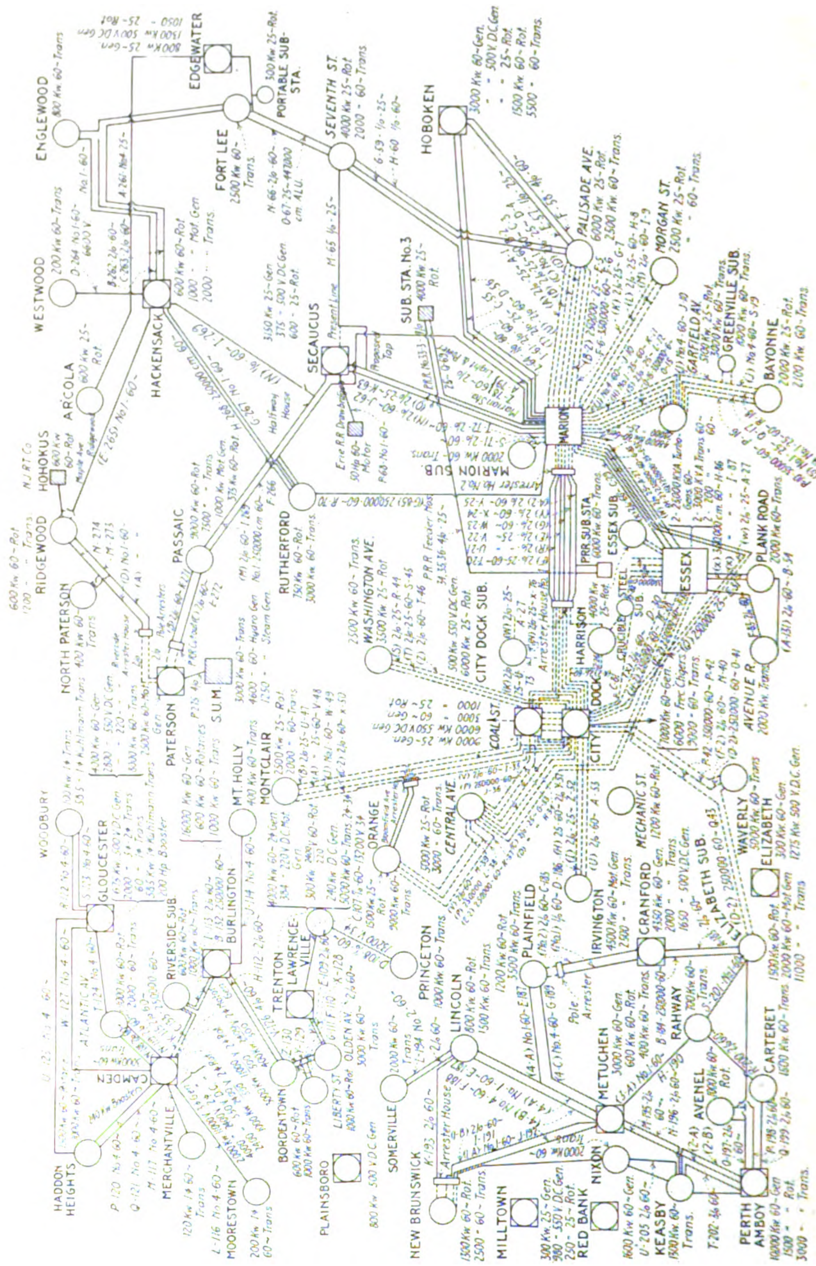
We have had no experience in grounding the neutral but it would seem to me that the proper place to ground it is in the generating station, and that resistances should be used so as to limit the current to an amount great enough to insure the operation of the relays in case of trouble.

Our 13,200-volt transmission system in this state is shown herewith.

The surge suppressor is installed in our Marion Station, which is our largest generating station. We also have surge suppressors installed in our Perth Amboy and Burlington stations.

The charging current for the feeders connected to our Marion station, which takes in what is known as the Northern Division, is approximately 75 amperes.

We have five per cent 13,200-volt feeder reactors installed on all 60-cycle feeders from Marion and Essex stations, with the exception that the tie feeders between our City Dock and Marion stations, and between



TRANSMISSION SYSTEM OF PUBLIC SERVICE ELECTRIC COMPANY WITH PEAK LOADS FOR WINTER OF 1914-1915.

our Essex and Marion stations, have 2.5 per cent feeder reactances at each end, making a total of 5 per cent between the generating stations.

Between our City Dock and Marion stations, we have seven three-conductor 13,200-volt tie feeders. At each end of these feeders we have a seven-section selective relay which cuts out the bad cables in case any trouble occurs between these two stations. On all other feeders we use standard makes of circuit-closing inverse time limit relays.

When a ground or short circuit occurs on a cable or aerial line, a test is made for location as soon as possible. If the ground or short circuit is of such high resistance that a good test cannot be made, the resistance of the fault is decreased either by further breakdown from testing transformer, or by reduction with 600-volt direct current. The location is then made by means of a slide-wire bridge using the loop method. The chief causes are mechanical injury to the cable, defective joints, water in the cable (probably caused by a previous breakdown somewhere near this same location) and high-voltage disturbances, cause unknown.

From Pacific Light and Power Corporation,
Mr. H. A. Barre, Elec. and Mech. Engineer.

The arrangement of the high-tension distribution has been such that it has been possible to operate alternately with the grounded neutral system and the ungrounded delta system. The experience with the ungrounded delta system has been so disagreeable that we have made up our minds that under our conditions a grounded neutral system is essential.

The determining conditions seem to be the number of miles of line and the capacity of apparatus connected to the system.

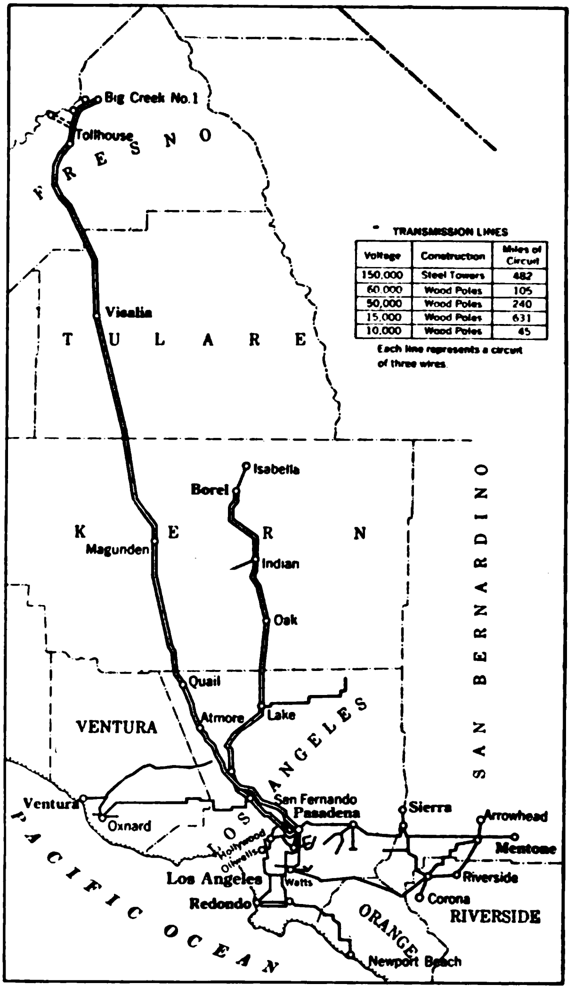
The business of this company consists of supplying power to the company's commercial distribution, which covers all classes of load and includes some 15,000-volt underground cable; and of furnishing service to two large railroad companies, each of which has a maximum demand of about 25,000 kw. The total system peak load for the past years has been 76,000 kw. at the generating stations.

The 150,000-volt, 240-mile (386-km.) line from Big Creek is served through delta-star connected transformers at the generator end, with the neutral of the high-tension side grounded, and delivers power through delta-delta connected transformers at the receiving station. One-half of these latter lowering transformers have a secondary voltage of 15,000 volts. The remainder have a secondary voltage of 60,000 volts. The reason for this arrangement is that the base of the company's distributing system is a very extensive 15,000-volt network. The close-in parts of this net work receive power from the substation directly at 15,000 volts. The remote parts are fed with 60,000-volt feeders.

The 15,000-volt network, including the lines of the two railroad companies, embrace about 1600 miles (2574 km.) of line. The 60,000-volt system at the present time has about 85 miles (136 km.) of line.

Connected to the 60,000 volt system through compensators are about 300 miles (482 km.) of 50,000-volt line. Fed from this line are about 45 miles (72 km.) of 10,000-volt lines, and 45 miles (72 km.) of 15,000-volt lines, which are not otherwise connected to the net work. These 10,000-volt and 15,000-volt lines were not connected during the time of trouble with the ungrounded delta system which is described later.

On account of the fact that it was desirable to make the lowering transformers of the Big Creek system of the same design for both voltages so that they could be connected in series for 60,000 volts or in parallel for 15,000 volts, the 60-kv. and 15-kv. systems are in phase, hence they require delta-delta transformations at the remote points where the 60,000-



TRANSMISSION LINES OF PACIFIC LIGHT AND POWER CORPORATION

volt feeders deliver to the 15,000-volt network. This precluded the possibility of a grounded star connection at the latter points of transformation.

Previous to the advent of Big Creek, the 15,000-volt system had been fed from a 40,000-kw. steam turbine plant of which the neutral was

grounded. After Big Creek commenced service, this steam plant was needed only in emergencies and the opportunity for establishing the ground through it was lost except during such hours as it might be operated. This left the 15,000-volt network without an established neutral, and it was found that whenever any trouble occurred which involved the accidental grounding of a 15,000-volt wire, the flow of charging current was sufficient to set up very serious surges in the system. These invariably caused breakdowns at more than one point on the system, sometimes three or four points, and the damage to the service and apparatus became a matter of most serious concern. These breakdowns were usually flash-overs or punctures of transformers and switch bushings or line insulators.

It happened that while this condition existed, a new station was being built at Vernon, in which were being installed, amongst other things, a bank of three 5000-kw. transformers with a voltage ratio from 60,000 to 15,000. As an experiment, the 15,000-volt side of this bank of transformers was connected in star with the neutral point grounded, and the bank connected to the 15,000-volt bus bars. The 60,000-volt side was delta connected, and being, therefore, out of phase with the 60,000-volt bus bar, was left idle; in other words, an idle bank of transformers having closed delta secondary was used to establish the grounded neutral on the 15,000-volt system. This bank had a very large capacity, full load being something like 600 amperes.

It was found that this effectively eliminated the surges and that after its installation whenever line trouble occurred the effects were localized in the section affected, and in practically every case the system of operation employed to sectionalize the net work, both automatically and manually, has served to protect the service. Some troubles have occurred on the 60,000-volt system, but since there is a ground established to it by connections to another plant, they do not at the present time appear serious.

My personal opinion is that this is largely due to the fact that the 60-kv. system is of comparatively small extent and when it grows, a system of connections to establish a grounded neutral of large current carrying capacity will be an absolute necessity.

My general opinion is that power stations and other sources of supply should always be operated on a grounded neutral connection having the generator side delta connected. The delta-delta system is preferable for receiving stations and distributing substations.

We have not found the installation of resistance in the neutral of any advantage. My opinion is that the difficulty of making a good ground answers the resistance question.

On the 150,000-volt Big Creek lines, accidental grounds are handled as follows:

When the operator at the power house sees the recording ground ammeter showing a ground, he reduces the generator field by cutting in a special rheostat installed for this purpose. As soon as the ground ammeter drops back to zero he cuts out the resistance and the voltage comes back to normal, and the automatic voltage regulator takes control. This resistance is not cut out all at once, but the time which elapses from the time the arc breaks until normal voltage is restored, is from five to ten seconds.

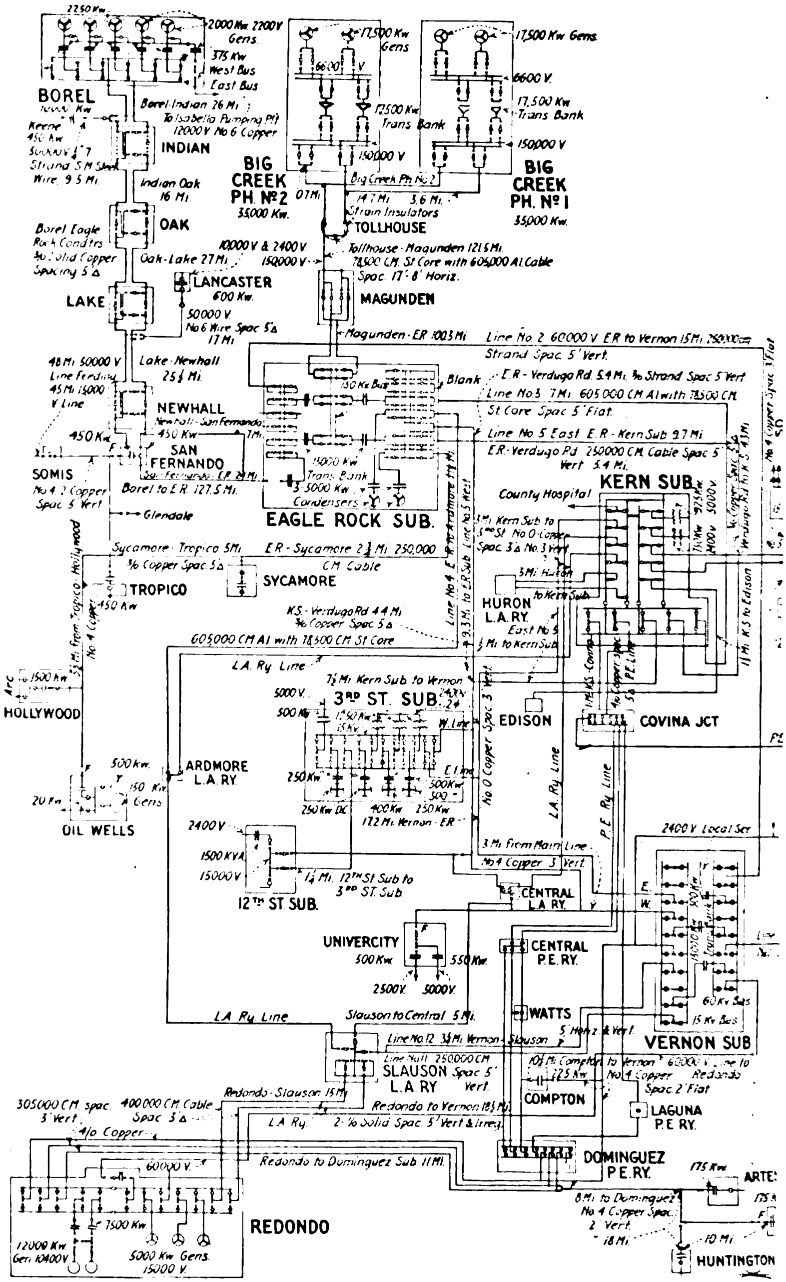
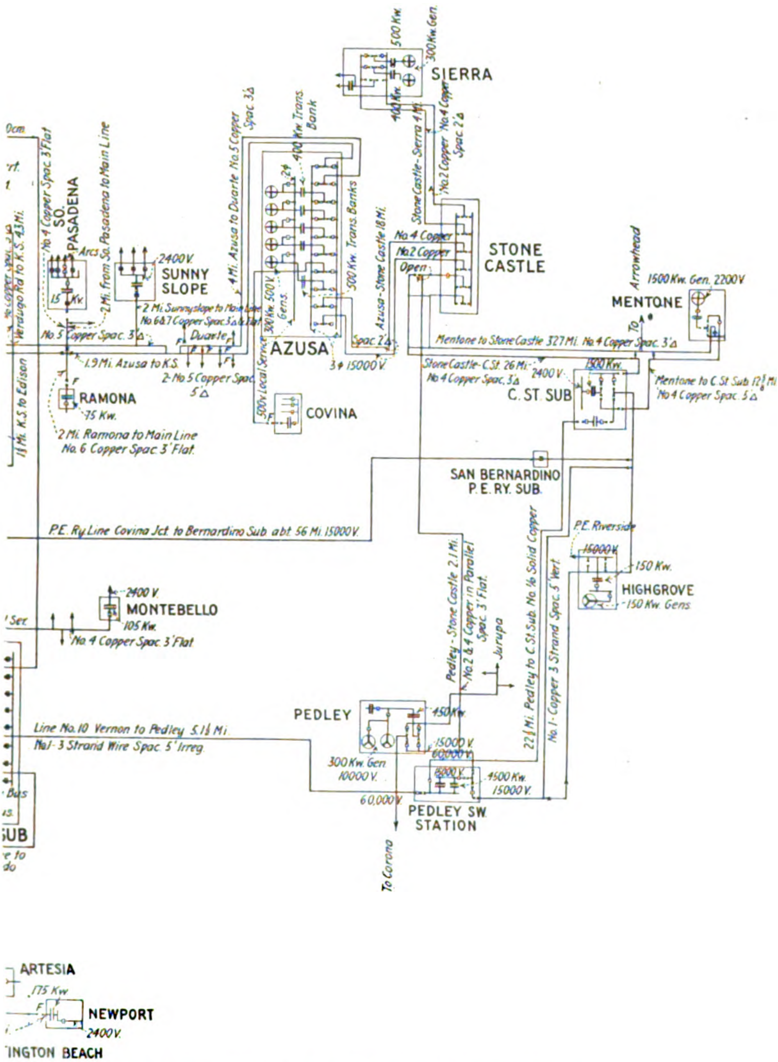


DIAGRAM SHOWING THE DISTRIBUTION SYSTEM



OF THE PACIFIC LIGHT AND POWER CORPORATION

At the receiving station at Eagle Rock the operator kills the field of condensers at once by opening the circuit of the automatic voltage regulator. As soon as he sees that the power house has overcome the trouble and the voltage is coming up again, he closes the regulator circuit.

Governors at the power house must take care of the speed when the load is dropped. They always do this.

For the remainder of the system on those lines which are controlled by automatic circuit breakers, the switches are closed after opening of trouble, and if the short circuit or ground is still on the line, the switch is left open and men sent out to find the trouble. Where the switches are not automatic, the above operations are performed manually.

On the 150,000-volt system from Big Creek, the troubles are entirely of two kinds:

First, the personal element, of which three cases have occurred:

(a) Where a man digging a well put in too heavy a charge of powder and blew some debris into the line.

(b) A tree was left standing too close to the line and in felling it, caused a ground.

(c) A farmer drove a hay stacker with derrick erected at a height of some 36 ft. (10.9 m.) above the ground into contact with the line.

Second, the other and more frequent cause of trouble, of which some twelve or fifteen cases occur each year, is the spilling over of insulators in the middle half of the line. We have not been able to determine the cause of these spillovers or locate any operating or climatic coincidents which would indicate their origin. They seem to occur at all hours of the day and night and under all weather conditions, but are absent from the end quarters of the line.

Outside of the 150,000-volt system, the greater number of troubles occur from personal interference, either accidental or malicious, of both employees and outsiders.

On a system containing so many miles of lines and nearly 100 substations, the opportunities for misunderstandings and mistakes are many. This is intensified by the fact that the operation of the lines and substations are under the control of three entirely independent corporations.

Another cause of trouble is the usual one of washing out of lines during floods and similar accidents, depending on the weather.

A considerable number of interruptions have occurred by reason of the continued failure of a certain class of pin-type insulators on the 50,000-volt lines, which have been in operation about ten years. There seems to be a continuous depreciation or weakening of these insulators, which becomes noticeable, in those parts of the line where the weather conditions are most severe.

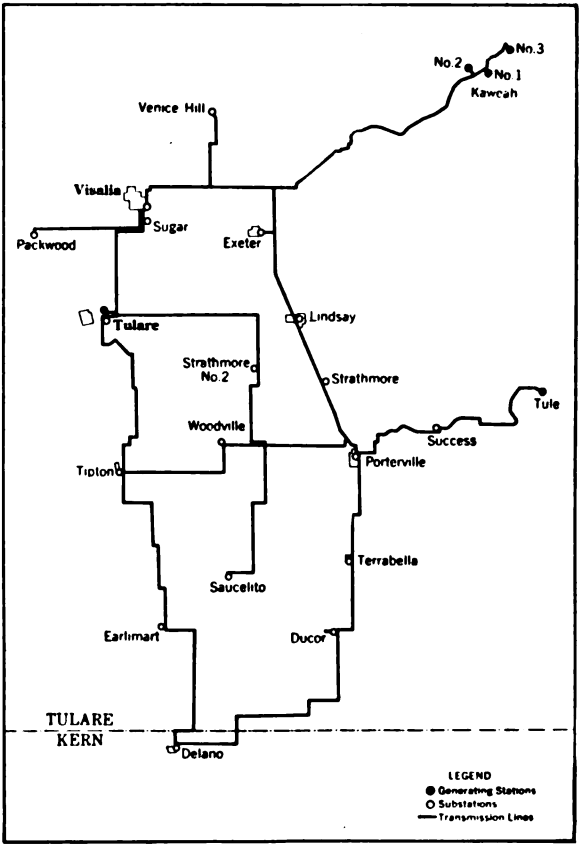
The suspension insulators used on some of the distributing lines have caused a number of failures, although careful inspection of the Big Creek line has so far been successful in eliminating the defective insulators in time to prevent trouble.

The only other serious cause of interruption is the combination of summer fog and dust, causing surface leakage over the insulator, which carries sufficient current to set the pole on fire. In the last few years, interruptions from this cause have been practically eliminated by the expedient of electrically connecting the insulator pins, which are of iron.

No complete detailed analysis of these various kinds of trouble has been made, so that I am not able to give you more than the above generalization.

From Mt. Whitney Power and Electric Company,
Mr. Fred G. Hamilton, Supt. W. Div.

This company is operating practically 200 miles of 33,000-volt transmission lines. The lines are arranged in the form of a figure eight and are fed by four hydroelectric and two steam plants.



TRANSMISSION LINES OF MT. WHITNEY POWER AND ELECTRIC CO.

The neutral is grounded on each hydroelectric plant, but there is no ground at the steam plants or any of the substations.

The elevation of the hydroelectric plants is practically 1150 ft. (350 m.) while the substations are located at an elevation of 350 ft. (106 m.)

It has always been our method of operation and we have no data upon non-grounded operation. We have experienced no particular difficulties particularly chargeable to the grounded system. We have had grounds

and short circuits on the transmission line which we cleared up by cutting out the faulty section, by trial, between the substations. The switching is controlled by a load dispatcher at the Visalia steam plant.

This system gives us very efficient service and the worst cases of interruptions are only of short duration. Since our voltage is comparatively low and we have had no experience on non-grounded operation, we are not in a position to give comparative data, which would be of much assistance. For our voltage we feel that non-grounded lines would probably give us as good service as our grounded system.

From The Toronto Power Company,
Mr. F. G. Clark, Chief Engineer.

The question of grounded or ungrounded neutral can be considered from different points of view.

Where drainage of accumulated electrostatic charges is required to avoid excessive d-c. potential, grounding is very effective as it will drain off all such charges to earth, while on ungrounded systems this will have to be taken care of by the lightning arresters. This phenomena is very unusual in the northern part of this continent, and is usually safely taken care of by the lightning arresters.

Continuity of service can be preserved by either one of the two systems depending entirely on local conditions.

Grounding should be applied:

Where a reliable selective relay protection is available cutting out a faulty line without causing a service interruption.

Where the lines have to be operated in parallel on the high-tension side and where the line insulation is unreliable.

In this case grounding will prevent the spreading of a breakdown on one phase of one line to other phases of another line thus avoiding a long total interruption.

Where this high insulation exists so that other phases can stand momentary over-voltage due to one phase flashing to ground or where the lines can be operated sectionalized from the high-tension side, the spreading of a fault from one line to another due to the momentary voltage rise on the sound phases as occurs on an insulated system, is not to be feared. Accordingly nothing can be gained from grounding in this case. On the contrary, grounding may cause unnecessary disturbances and interruptions, whenever one phase only is affected which would be particularly detrimental to continuity of service where no reliable selective relay protection available.

The decision on the question of solid or resistance grounds should be guided by the line insulation and by the ability of the apparatus to withstand short circuit strains. Where low and unreliable insulation on the line is the prime object of grounding and where the equipment is built to resist effectively any short circuit strains, solid grounds should be used.

Where, however, the insulation is high and reliable and where the equipment may be somewhat mechanically weak, a ground resistance will be desirable to reduce the mechanical strain of single phase short circuits.

I would further advise that our transmission system from Niagara Falls to Toronto is composed of four circuits operating ungrounded at 60,000 volts. The transformers on either end are delta connected.

From Puget Sound Traction, Light and Power Company,
Mr. G. E. Quiman, Engineer, Seattle Division.

The four hundred odd miles of high-tension transmission lines of this company are delta connected and operated without grounds.

It is our opinion that probably the chief advantage of grounding the neutral of a high-tension transmission system, is that it eliminates most of the trouble experienced on an isolated system from arcing grounds. The principal disadvantage of grounding is that line trouble more frequently results in interruptions to service. It is our experience that the insulating qualities of wood poles and cross arms make it possible to retain a line in service until the defective point is located and frequently until arrangements can be made to take the line out for repairs.

Even insulator failures resulting from arcing grounds seldom cause serious service interruptions where the lines are carried on wood poles.

We are inclined to believe that where all important business is served from duplicate transmission lines, the grounded system is preferable, but where single lines have to be depended upon the isolated system makes possible greater continuity of service.

From The Colorado Power Company,
Mr. Norman Read, Asst. General Manager.

The Colorado Power Company is at present operating both its 100 kv. transmission and 13 kv. distribution systems connected in delta and with no artificial neutral.

From The Montana Power Company,
Mr. H. H. Cochrane.

This company operates ungrounded, and believes this method preferable. Telephone operation is very satisfactory.

The typical protection for two transmission lines in parallel consists of three pole overload relays at the generating station end of the line, operated by three current transformers in each line, and three-pole reverse current relays operated by three current transformers and potential trnasformers in each line. The system has sufficient line charging current to trip relays when one wire of the system is grounded.

From Utah Power and Light Company,
Mr. Markham Cheever, Chief Engineer.

From our principal generating stations power is transmitted at 130,000 volts to a central substation near Salt Lake City. At this substation the voltage is reduced to 44,000, and numerous feeders make connection with an extensive and complicated network of 44,000-volt lines. Everything is now operated with neutral ungrounded and we see no reason for changing the 130,000-volt system, since up to the present time there have been during two year's operation, practically no operating difficulties.

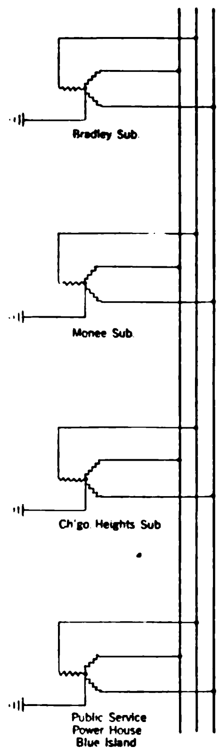
Upon the 44,000-volt system we are considering the installation of a suitable grounding compensator located at the main central substation for the purpose of facilitating automatic sectionalizing of disabled lines and for the reduction of high-voltage strains.

Our earlier experience in this territory with 44,000-volt systems of moderate sizes indicated the advisability of operating with neutral un-

grounded, since there were many cases of grounds which would clear themselves without disturbing service and some cases of dead grounds which permitted the continuance of operation until repair could be made. During the winter of 1912 and 1913 a number of systems were paralleled and since that time many extensions have been made. With the enlarged system we are finding that practically all cases of grounds develop into serious trouble and it is often difficult to localize the disturbance.

From the Chicago and Interurban Traction Company, Mr. Robert J. Bell, E. E.

We have a 33,000-volt three-phase 25-cycle transmission line, extending from the Public Service Co. power plant at Blue Island, to Bradley Ill., a distance of about 45 miles (13.7 km.) This line consists of three No. 4 hard drawn copper wires placed on 35-ft. (10.6-m.) cedar poles spaced 110 ft. (33.5 m.) apart.



BRADLEY SUB-STATIONS TRANSFORMERS 1950-430 VOLTS. POWER HOUSE TRANSFORMERS 9000-33000 VOLTS

We have three substations on this line with one 500-kw. synchronous converter in each of these stations. The Bradley substation has, in addition to the converter, a 500-kw. frequency changer, 25-cycles to 60 cycles.

Our transformers are Y-connected on the primary in all the substations. At the power plant they are Y-connected on the secondary side.

We have a telephone line on the same poles, but do not experience any serious trouble. There is some noise but not enough to interfere with service. This line is transposed at every fifth pole. The neutral connection at the transformers is grounded, and we have not experienced any trouble therefrom. We have experienced one great advantage by grounding the neutral, that is, in case of line trouble, where one of the phase wires becomes grounded, we are able to test out and find what phase it is, then have the disconnecting switches pulled out on this phase at each end. We are then able to operate on the remaining two wires by the use of the grounded neutral.

This system has saved us a great number of hours of shut-downs and we have had no trouble caused by this system of operation.

As to the advisability of grounding the neutral, while it may not work successfully on all systems, I think it worth while to try it out, especially if the transformers are not loaded too heavy.

We operate grounded at the substations and at the power plant.

We lost some insulators during electrical storms (which having the neutral grounded may encourage). All our trouble has been from direct lightning strokes.

It makes our telephone line a little noisier when we are working on two line wires than otherwise.

A general layout of the line with the transformer connections is shown herewith. We have an overload relay on our oil switch which is set to trip out on normal overload, and we make use of the current to ground when we are using two line wires.

These grounds are cleared by linemen sent over the circuit. The causes are various, but very frequently can be traced to a broken insulator. I think no current flows to ground through the ground connection but have never made any test to that effect.

From Alabama Power Company,
Mr. W. E. Mitchell, Operating Manager.

Our experience here in Alabama has caused us to become firm advocates of the grounded neutral on our high-tension system, and grounded solidly without any resistance whatever. This is based on about nine months of operation with it ungrounded and a year's operation with it grounded. This matter is discussed somewhat briefly by Mr. Dewey and myself in a paper which we read before the S. E. Section of the N.E.L.A. in September of this year. We found that our insulator troubles in the way of breakdowns and flash-overs were much worse and much harder to locate and control when ungrounded than when grounded. Grounded neutrals also made it possible to use the selective relays for cutting out immediately any section of line which might be in trouble. The grounding of the neutral turns any arcing ground immediately into a phase-to-neutral short circuit, which is much simpler to handle and to relay for than an arcing ground on an ungrounded system.

From The J. G. White Engineering Corporation,
Mr. C. D. Gray, Asst. Electrical Engineer.

My personal opinion is that systems up to about 38,000 volts should be operated with isolated delta connections, although this depends upon the local conditions under which the system under discussion might be connected. For systems above 38,000 volts I believe the star connection with grounded neutral to be the best, although in this case also the local conditions would influence a decision as to whether it should be star or delta. The locality in which the line is to be operated I believe has a great deal to do with it, and also the chances of interference with telephone telegraph and other systems of this kind.

Our experience has been that the delta system has less influence on telephone and signal circuits than the grounded neutral connected system. A great disadvantage of the star-connected grounded neutral system is the fact that the circuit breakers are thrown out on trouble on any one of the three wires of the system, and that it is practically impossible to operate with one wire down, or with one transformer out of service in a bank of three, unless the conditions of grounding are very favorable, where as with the delta system the open delta connections of transformers can be used temporarily at least without causing a great deal of trouble.

Another point in favor of the star-connected grounded neutral system is the fact that trouble on the line can be located better by means of the Nicholson or other similar testing method. The line insulation has been

so improved in the last few years that it is now possible to operate delta connected whereas previously it was not possible on account of the insulators, it being necessary to reduce the potential to ground in order to favor the insulators.

With regard to the operation of three-phase systems, I agree very well with the paper of Messrs. Jollyman, Downing and Baum, given before the Institute on May 29, 1914. This would be especially true with any system operated with pin-type insulators similar to that of the Pacific Gas and Electric Co's. system.

In conclusion I would say that I am not greatly in favor of one system over the other, but that the local conditions would largely influence a decision in the matter, and it seems to me that it is more a matter of experience from operation in any particular section of the country rather than the result of theoretical decision.

From Mr. Charles E. Waddell,
Consulting Electrical Engineer.

The two high-tension systems with which I am most familiar do not ground the high-tension neutrals: these systems are the North Carolina Electric Power Company, which serves Western North Carolina and which operates at 66,000 volts and 6600 volts, and the Florida Power Company which serves the west coast of Florida in the mining district and which operates at 60,000 volts.

My inclination, which is tending toward a fixed opinion, is that it is possibly wise to ground the secondary system of small substations supplying consumers regardless of the secondary voltage, be it even as high as 2000, the object being the protection of life and property. On the other hand I am forced to conclude,—certainly for this vicinity,—the grounding of the neutral of high-tension transformers at the tie-in substations would be a menace rather than a protection. As you are fully aware, the recent general practise is to ground the secondaries of the instrument transformers used in connection with the switchboards. While this has proved a great protection as far as life is concerned, I have found that the practise has increased the number of burnouts and really interferes with continuous service.

A considerable number of additional replies were received which contained no information of special interest.

An examination of the above replies emphasizes what is perhaps the proper point of view on this subject, namely, the effect of grounding the neutral of a high tension system will be different in different sorts of systems, it may be an advantage in some and a disadvantage in others. Furthermore the effect of grounding through a resistance is different from the effects of grounding directly. Each case must be considered on its merits and most of the probable cases are illustrated by the above replies.

The neutral may be grounded in different plants for various reasons:

(a) To prevent throwing full line potential on other line wires by a ground on one line.

(b) To enable relays to operate quickly and surely or selectively.

(c) To prevent arcing grounds.

(d) To locate breakdowns.

(e) To take the place of one line wire on a three phase system when this wire may be interrupted. This requires the disconnection of the grounded wire.

(f) To enable grounds to be extinguished by the Nicholson automatic system of grounding through a fuse.

When the ground connection is specifically omitted it is usually to enable operation with one line grounded and thus minimize interruptions.

Actual practise shows that grounding is more often resorted to on high voltage, and in large and complicated systems. Wooden pole-wooden crossarm lines below 60,000 volts offer the best chance of operating successfully with one line grounded.

In conclusion attention is called to the very full and illuminating reports of several of the companies sending replies. The thanks of the Committee is due to these and the others who have cooperated with the Committee in collecting the data reported.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

(*Subject to final revision for the Transactions.*)

THE RESTORATION OF SERVICE AFTER A NECESSARY INTERRUPTION

BY F. E. RICKETTS

ABSTRACT OF PAPER

Since electricity has become recognized as the most important means for transmitting energy the value of uniformity in voltage and frequency has become more and more apparent. The phenomenal growth during the last few years in the electrical industry has been due as much to the marked advances in the methods for maintaining a uniform service as to any other cause. During this period of rapid development many papers have been written, setting forth different ideas as to ways of providing against interruptions. At the beginning, these ideas varied greatly, but now there seems to be some hope for a more uniform practise as to this type of apparatus.

In writing this paper I have assumed that the field has been pretty well covered so far as the prevention of interruptions goes, but have to call attention to that class of interruptions which so far have been and will likely continue to be unavoidable; and have endeavored to describe certain means whereby the effect of unavoidable interruptions may be reduced to a minimum.

GENERALLY speaking, alternating-current generators cannot be injured by overloading for a few minutes, and since the sudden interrupting of a circuit carrying heavy currents tends to produce abnormal voltages it is very advisable during abnormal conditions on an electrical system to keep all the switches closed except when the opening of a switch or switches is necessary in order to disconnect some section of the system that has become permanently disabled. Especially is this true when we consider the delay usually experienced in restoring service on a portion of a system that has been temporarily cut out, even though there may have been no trouble on that portion.

Since the amount of service affected by the opening of a switch is in proportion to the nearness of the switch to the generator, the importance of keeping the switches closed increases as we approach the generators; consequently the generator switches should be arranged so that they will never open due to any overload, however, great the current may be. But for the chance of trouble within the generators themselves, the switches con-

Manuscript of this paper was received March 21, 1916.

trolling them would be better made non-automatic; however, with such an arrangement, in case a short circuit or a ground should occur within the generator, the service would be seriously disturbed until the operator could open the switch by hand, and there would also be a possibility of the generator being seriously damaged if not destroyed.

Fig. 1 illustrates an ideal scheme for the protection of generators. The generator is three-phase, but in describing the scheme we need only consider a single phase as the action of the others will be the same. At each extremity of phase *A* there is a current transformer, transformer *A*1 being near the oil switch and transformer *A*2 being in this case near the neutral, so that any current passing completely through phase *A* will produce in the

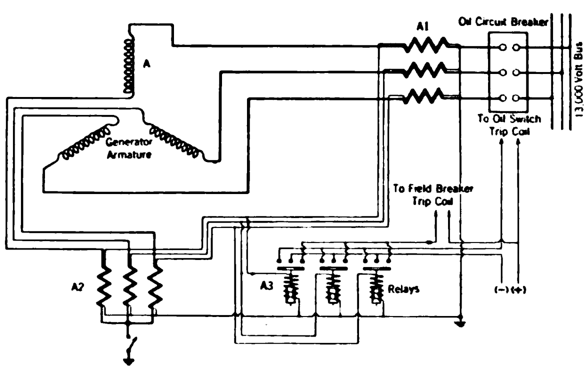


FIG. 1—CONNECTIONS FOR RELAYS ON GENERATORS

secondaries of the two transformers, currents that are exactly equal and in phase, the transformers having equal ratios and connected so that their secondaries will work in series with their instantaneous voltages in the same direction. Then if a relay such as *A*3 is connected with its actuating coil between the two wires connecting the transformers, and its contact circuits connected to both the trip coil of the switch in the armature circuit and the trip coil of the switch in the field circuit, the terminals of the actuating coil of the relay will always be at the same potential as long as there is no leakage of current in the winding of phase *A*, regardless of the load on the generator or whether it is operating as a generator or motor. Therefore, as long as there is no trouble in the generator no current will flow through the coil of the relay and there will be no tendency to trip the switch,

but just as soon as current starts to leak from phase *A* to one of the other phases or to ground, there will be a difference in the value of the current flowing through the two transformers, which difference will be represented by a current in the secondary of one transformer, but not in the other; therefore this unbalance in the secondaries will have to flow through the actuating coil of the relay which will cause its contacts to close and instantly open both the armature circuit and the field circuit, thereby not only preventing current from feeding from the bus into the damaged generator, but also preventing the damage that would have been caused by current generated by this generator had the field circuit remained closed.

Now, that we have the generator switches arranged so that they will not open on overload, so long as the generator is in working condition and the other switches on the system assumed to be equipped for selective operation, let us consider what would happen if, when an arc occurs between two conductors of the system at a point where the insulation will not be permanently impaired we simultaneously interrupt the field circuits of all the generators for a short interval of time; say, one or two seconds. When the field circuits of the generators are opened, the voltage of the system will very quickly drop to near zero, especially is this true when the short circuit is severe, in which case the heavy armature current will tend to demagnetize the generators, even before the field circuits are opened. This drop in voltage will be much more rapid than could be accomplished by reducing the voltage applied to the field circuits while the field circuits remain closed since then, as the magnetism of the fields decrease there would be induced in the closed field circuit a voltage that would oppose the decrease in field current. Figs. 2 and 3 give a comparison of the relative time required for the armature voltage to die out when the generator field is opened and when the exciter field is opened. Fig. 2 is for opening of the generator field and Fig. 3 for the opening of the exciter field. If the exciter voltage were lowered by cutting resistance in the exciter field, the time would be still longer. By the time the fields close the arc will have ceased, and as the current builds up in the fields the armature voltage will rise gradually from zero to normal, with total absence of voltage surges and an armature current not exceeding 200 per cent normal. As the armature voltage rises to normal, the service on the entire system will be restored. However, to accomplish the best results, special arrangements of

relays should be provided, and when there are synchronous motors on the system, special features should be incorporated in their design.

To assist in the detail description of this system in practise, Fig. 4 is shown, which for practical purposes illustrates the system as it has been successfully used by the Consolidated Gas, Electric Light and Power Company, of Baltimore, for the past three years. A motor *M* is connected through a train of gears

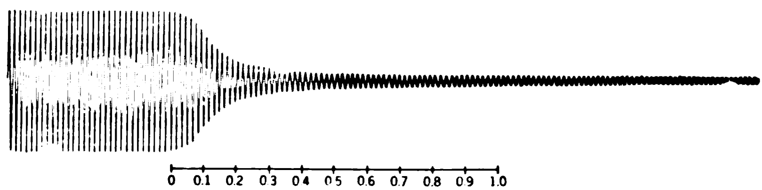


FIG. 2

to a dial switch *A* in such a way that when the motor is in operation the dial makes one complete revolution in one minute which is the time required for one cycle of operation of the system. The motor is set in operation in response to either of the relays, 1, 2 or 3 which are connected to current transformers in the armature leads of at least one generator that is in operation on the system to be protected. These relays are connected to transformers in the generator leads rather than in any other

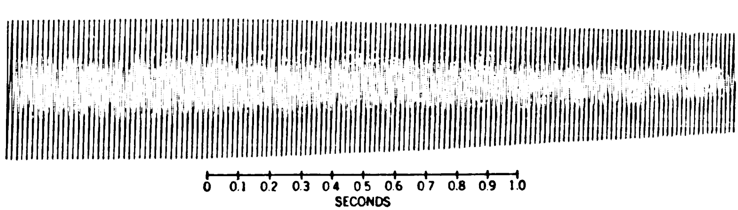


FIG. 3

part of the system for the reason that they will then always be subjected to the same current during a short circuit regardless of the number of generators in service, whereas, if they were placed in the outgoing circuits they would, during a short circuit, be subjected to a current that would be in proportion to the number of generators in service at the time. The action of the relays to start the motor is delayed by a definite time limit relay 4 for two seconds in order or give certain of the selective relays

on the system time to operate or cut out a minor circuit that may be short circuited, but this time must be less than that required to operate the relays controlling the major part of the system. Very soon after the time-limit relay has caused relay $R1$ to pick up and start the motor, segment B which is carried by the rotating dial will touch a contact which will apply current to relay $R1$ during one complete revolution of the dial independent of the time-limit relay. This prevents the motor from stopping after it has once started until it has completed one cycle. Immediately after $R1$ is locked a button on the dial touches a contact that closes relay $R2$, which trips out all the field switches, and

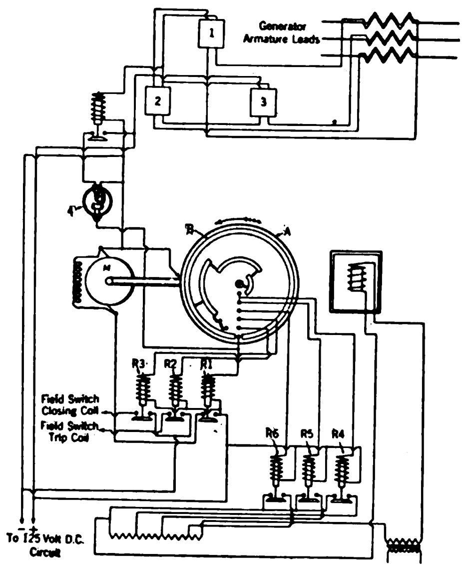


FIG. 4

about two seconds later another button on the dial touches a contact that closes relay $R3$ which closes all the field switches. The voltage regulator will boost the exciter voltage to a maximum, while the fields are opened so that when the fields are closed the field current will build up to a maximum which is very desirable, as the time required for the generators to pull in step varies inversely as the strength of the field currents. However, when the generators pull in step the voltage may rise so rapidly that the regulator will not be able to control it, therefore, to prevent the voltage from rising too rapidly and overshooting, the relays, $R4$, $R5$ and $R6$ are controlled by the segments near the center of the dial so that during the first one-third cycle of opera-

tion, one-half the resistance in series with the voltage-regulating coil of the regulator will be short circuited and the resistance will be cut in circuit in steps as the dial rotates, all of the resistance being in circuit at the end of the cycle.

Therefore, since the regulator operates to maintain a constant current in the voltage coil, the voltage will be maintained in proportion to the resistance in the circuit of the voltage coil; that is, the voltage will be restored to normal gradually, which is of great importance in pulling the motors on the system into synchronism.

During the operation of the device, the induction motors will slow down and come back to normal speed, but the relays controlling them should be set for a rather high current, say 400 per cent load to prevent them from tripping before the motors are up to speed. This high setting will not be dangerous as the motors will stand a heavy overload for a few seconds without heating to a dangerous temperature, and in case a motor burns out sufficient current will flow to trip the relay.

Synchronous converters present a more difficult problem since they lose a great part of their torque when they get out of phase, and their polarity on the direct-current side depends upon the polarity of the brushes when they come into synchronism there being an equal chance that they will have one polarity or the other, since the polarity of the brushes changes every time the armature gains or loses one pole.

This reversing may be overcome by exciting the fields from an external direct-current source which is not disturbed by the short circuit so that the converter armature will not lock in step when the brush holders are of the wrong polarity. This separate excitation need not be equal to that at which the rotary normally operates; in fact, it should not be of full value as it may cause the converters to flash at the brushes as they are pulling into synchronism. In most cases 25 per cent full value of field current will insure the polarity being correct. Fig. 5 illustrates one method that has been successfully used to accomplish the above result. A converter 1 is connected to the positive and negative buses through automatic circuit breakers and has its neutral grounded. There is also a storage battery 2 connected to the buses to take the load during short interruptions on the alternating-current system. When the fields of the generators open and the voltage decreases, current will flow from the battery into the converter until the breakers open. Then, since the voltage of the rotary is not sufficient to hold up the relay *R*1, the plunger

of this relay will drop, opening its own circuit and closing that of relay *R*2 which connects the negative bus to a point between the field coils and the rheostat, so that current will flow from the ground through the transformers to the armature and thence through the field coils and rheostat in multiple to the negative bus, the voltage impressed on the field coils being half normal and in the direction to give the proper polarity at the brushes. Therefore, when the converter comes up to speed it will be ready for service.

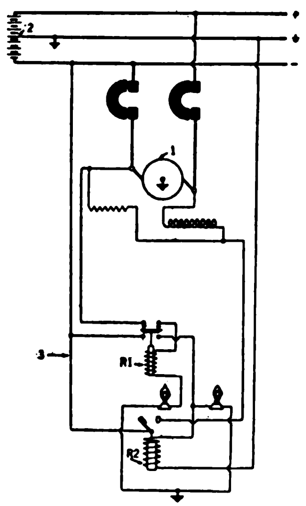


FIG. 5

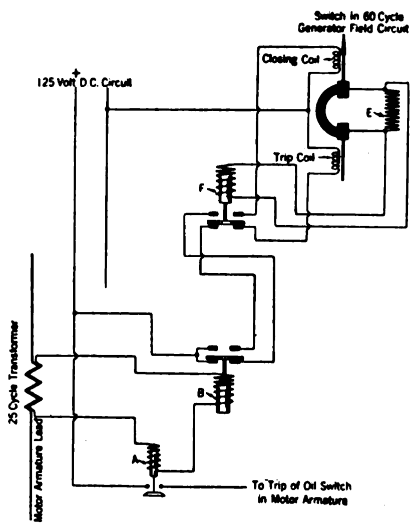


FIG. 6

Generators	Resistance	Capacity
5000 kv.a.	0.5 ohm	150 amp.
3000 "	1 "	75 "
1000 kw.	2 "	50 "

When no battery is used on the bus, a small battery capable of furnishing the field current should be connected between the neutral and wire marked 3 which would then not be connected to the negative bus. In order to prevent the relays controlling the a-c. side of the converter from tripping while the converter is out of synchronism, they should be set for about 400 per cent normal load.

With synchronous motors the problem is more difficult, since they lose a part of their torque as soon as they get out of synchronism. In this case it becomes necessary to reduce the load to a point where the motor will pull in step. One method of accomplishing this is shown in Fig. 6 which illustrates the connections for reducing the load on a motor-generator until the

motor can pull in. A single armature lead is shown, as the connections to the others are similar. In this armature lead is a current transformer which furnishes current to two relays one of which *A* is connected to trip the main switch controlling the motor, is set for 400 per cent load and should have an inverse time characteristic such that it will trip in about one-third of a second at the maximum current the motor will feed into a short circuit; then it will not trip under heavy load or when a short circuit occurs on the system, but will act very quickly when trouble occurs in the motor. This protection could also be accomplished by the scheme recommended for generator protection earlier in the paper; however, the arrangement shown in Fig. 6 has the advantage of protecting the motor should it get out of step and for any reason be unable to regain synchronism. There is also in the circuit of the current tranformer a relay *B* which is so designed that it will pick up at a current corresponding to 200 per cent load of the motor, and after it has once picked up, it will not drop till the load on the motor is normal. Responsive to the relay *B* is a switch in the field circuit of the generator, which has connected in parallel with it a resistance *E* that, when in circuit, will limit the load on the generator to a point where the motor will pull into synchronism. Therefore, as the voltage on the system builds up after an interruption, before the current in the motor is great enough to operate relay *A*, relay *B* will pick up and trip the field switch, which will cut in the resistance *E* and thereby limit the load on the motor to a point where the motor can pull in without operating relay *A*. It will also be noted that there is a relay *F* which picks up in response to the voltage across resistance *E*, and opens the circuit of the trip coil of the field switch and closes the circuit of the closing coil, so that when the motor pulls into synchronism and the current decreases to normal the field circuit breaker will be closed and the voltage on the generator will be restored to normal; also the voltage across relay *F* will drop to zero and it will reset itself.

The design of synchronous motors affects to a great extent their ability to pull back into synchronism, the greatest item being the resistance of the damper winding. Some motors will not pull back without any load with full voltage applied to the armature, while others with properly designed damper windings will pull back as much as 65 per cent of full load with only 80 per cent of full voltage on the armature. I know of one machine that would not pull in without load that pulled back with full

load after its poles had been replaced with ones with very low resistance dampers. However, these low resistance dampers give very low torque at low speed and make it practically impossible to start the motor by applying low voltage at normal frequency to the armature, making it necessary to start with an induction motor. When a heavy current flows in the armature of a synchronous motor while it is out of phase, the fields are subjected to a considerable stress by induction and it is therefore advisable, though not necessary, to insert reactors in the armature leads. This reactance should bring the total of the circuit to about 20 or 25 per cent, and can be provided in the winding of the motor in new machines. This reactance may seem rather high but the motors can be operated at unity power factor under which condition it will have no bad effect, and when the motor gets out of synchronism, the inductance of the armature will be high and its voltage will be in phase with that of the reactance, therefore the voltage across the armature windings will be materially reduced. This is shown graphically in Fig. 7. *A* shows the distribution of voltage between the armature and reactance when the motor is operating at 100 per cent power factor while *B* shows the same when the motor is running out of synchronism.

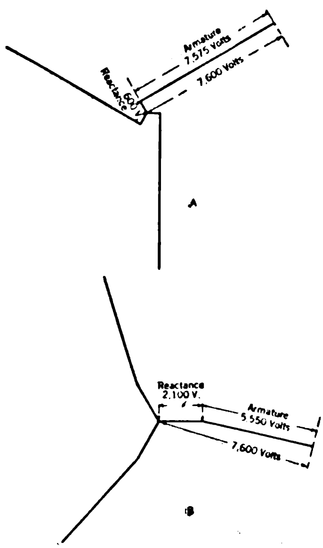


FIG. 7

Fig. 8, which shows a portion of a voltmeter chart taken at a generating station protected by this system during an electrical storm, illustrates the effect of lightning strokes on the service. The voltage was compensated for constant voltage at the supply point, therefore the shape of the curve shows the amount of load dropped and the rate at which it was restored.

The troubles at 4.14 and 4.18 were cleared by the fields being opened after the trouble had been on for four seconds. The trouble at 4.22 was cleared by other devices before the short circuit had been on long enough to cause the fields to open. It will be realized that the instant a severe short circuit occurs the substation machines begin to slow down and, when the fields

are set to open after four seconds, will be considerably below speed even before the short circuit is cleared, which adds to the delay in restoring normal conditions.

Fig. 9 shows a section of a voltmeter chart recorded at the same generating station as that shown in Fig. 8. Here the fields of all the generators were opened for one second while there was no trouble on the system, and it will be seen that there was no loss of load. It will be evident that if the fields were set

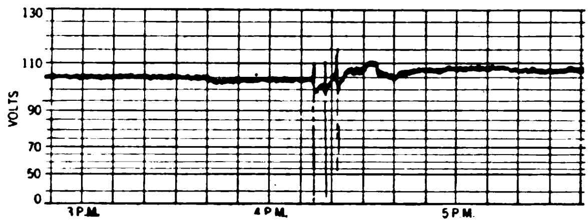


Fig. 8—Voltmeter Chart, June 21, 1913, Holtwood Power Station

to open instantly when a short circuit occurs, the system could be restored to normal with no more disturbance than would be caused by a short circuit that was cleared by the opening of an oil switch set for one or two seconds. However, in this case the overload relays would have to operate after the fields closed, when the trouble was of a permanent nature.

In practise, this system has proved of great value in clearing

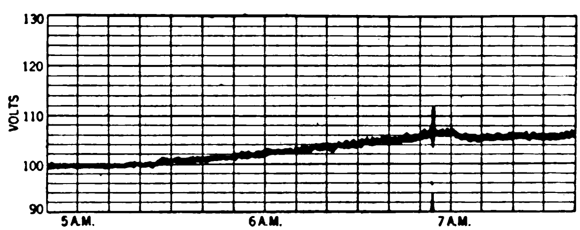


Fig. 9—Voltmeter Chart, Aug. 7, 1913, Holtwood Power Station

short circuits in the main bus structure, such as are sometimes caused by the failure of an oil switch or the accidental starting of an arc between buses. A further advantage is gained in starting a system after a general shut down, which can be done by closing all the alternating current switches while the fields are open, and then, when the fields close, all the generators will synchronize and bring the entire system up to normal, no telephoning being necessary, as the voltage will build up gradually and therefore

not damage any machines that may be left in service. This may be done even in cases where the service has been off for 10 or 15 minutes. When there are several generating stations operating in parallel there is no difficulty in getting the field breakers of all generators open at the same time, since the short circuit strikes all the stations simultaneously. If some of the breakers open a little before the others or if some of them do not open at all there is no bad effect.

Up to this point I have discussed only that class of interruptions that affect the entire system. There is, however,

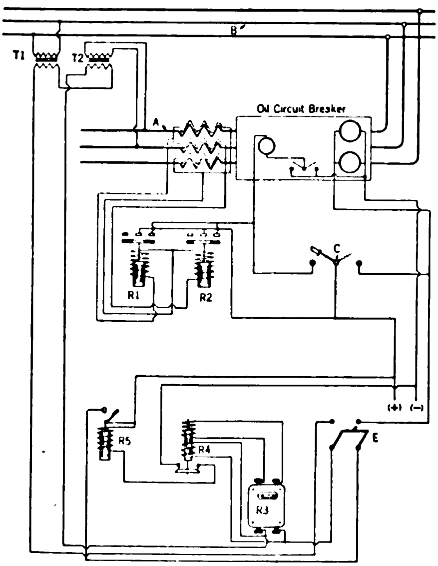


FIG. 10

another class which affects only a minor part of the system, for example alternating-current distribution feeders that are not tied in with other feeders after they leave the station. More than 50 per cent of the short circuits on these feeders are of a temporary nature, and therefore clear themselves as soon as the feeder trips out; but by the time the operator can close the switch again the motors have shut down. This in effect gives an interruption of several nimutes as the customer will be slow in starting up. Since an arc breaks within a fraction of a second after the voltage is cut off we may, by closing the switch quickly, prevent the motors from shutting down.

Fig. 10 illustrates a system that has operated very satisfactorily

to clear temporary short circuits on distribution feeders, when the short circuits are of such a nature that they will not re-establish themselves after the arc is once broken.

A feeder *A* is connected through an electrically-controlled oil switch to a station bus *B*. The switch *C* is for operating the switch manually, and relays *R*1 and *R*2 are for tripping the switch in response to current in the feeder, and serve the purpose of the usual overload relays. Transformers *T*1 and *T*2 are

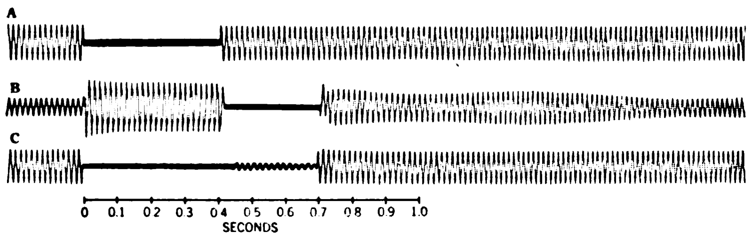


FIG. 11

connected one on either side of the oil switch, and in such a way that when the oil switch is closed their voltages will oppose each other, and therefore there will be no voltage impressed on relays *R*3 and *R*4. Then, when an arc occurs on the feeder, either of the relays *R*1 or *R*2 may trip the switch but as soon as the current is interrupted by the oil switch the voltage on the two transformers *T*1 and *T*2 will become unbalanced, which

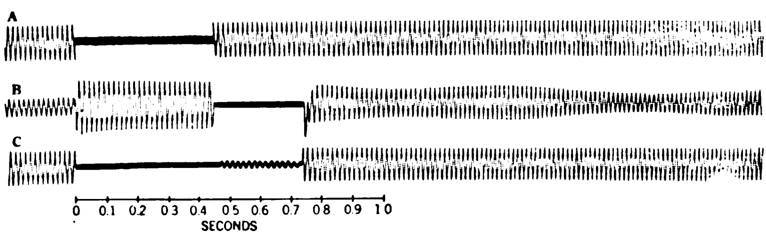


FIG. 12

will cause current to flow through relays *R*3 and *R*4; *R*4 will pick up instantly, but *R*3 being a time-limit relay will start to move but will not close its contacts for a predetermined time. When relay *R*4 closes its contacts, current will flow through relay *R*5, which will close its contact, and thereby close the oil switch. If the short circuit is still on the feeder when it is made alive, relays *R*1 and *R*2 will trip the switch again and *R*4 and *R*5 will close the switch as soon as the potential across the switch is

unbalanced. This opening and closing of the feeder switch will continue until the relay $R3$ closes its contacts, thereby short circuiting the upper coil of relay $R4$, which will prevent this relay from further operation until the voltage across $R3$ has been reduced to zero for sufficient time for it to return to its starting position. This is done after the trouble on the feeder has been cleared by opening switch E and closing the oil switch by means

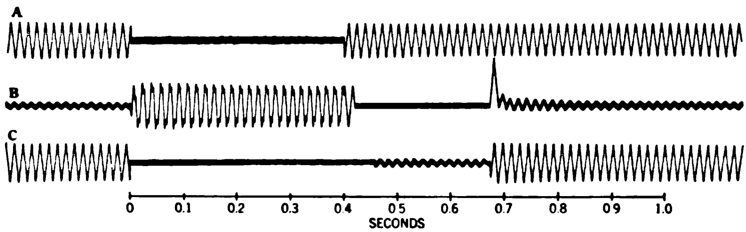


FIG. 13

of switch C; then the system can be put in operation again by closing switch E. If the arc breaks the first time the oil switch opens, $R3$ will return to its starting position making the apparatus self-setting.

In order to illustrate the accuracy with which this system operates, and its effect on the service, I have shown oscillograph records, Figs. 11, 12, 13, 14 and 15, which were taken on a 6600-volt system protected by this method. The arc was

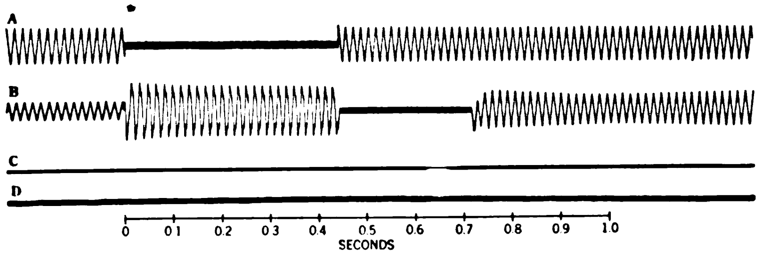


FIG. 14

started by throwing a one-inch (2.54 cm.) spark gap, short circuited by a fuse wire, across the circuits.

In Figs. 11 and 12, A shows the bus voltage B the current in one leg of a 200-h.p. induction motor carrying full load, and C the voltage on the feeder. To make the test most severe, the short was made near the switch and the load on the motor was provided by a direct connected generator supplying current to a resistance, so that the fly-wheel effect would be very small. It

will be noted that the time of operation was the same in each case and that the load was not very great after the operation. The conditions under which Fig. 13 was taken were the same as for Figs. 11 and 12, except the motor was running idle. In Fig. 14, *A* gives the voltage on the bus, *B* full-load current in the motor, *C* the voltage of the direct-current generator and *D* the zero line for *C*. It will be noted here that the direct-current

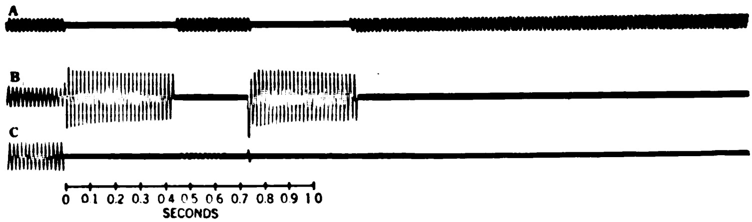


Fig. 15

voltage remained practically constant showing that the speed of the motor did not drop off materially. Fig. 15 was taken under the same conditions as Figs. 11 and 12 except the spark gap was made so the arc would not break. This shows how the number of operations was limited.

Fig. 16 shows the operation of the system with a later type oil switch; *A* is the voltage across the switch and therefore shows

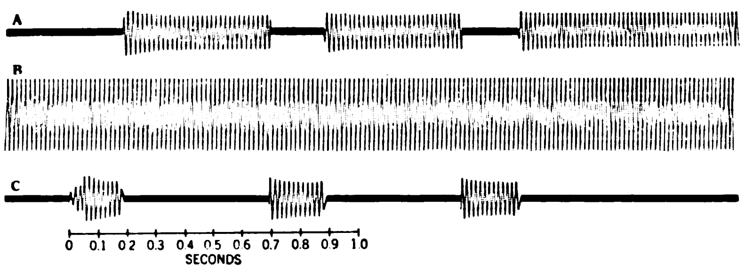


Fig. 16

the time the switch was open, *B* is a timing curve taken from a circuit of 62½ cycles and *C* shows the current in the short circuit. It will be noticed that the switch opened much quicker and closed slower than the old type switch used in the other tests; the total time of operation, however, was about the same.

The tests shown above have been repeated many times and in no case has the time required for similar operations varied more than one fiftieth of a second.

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

THEORY OF PARALLEL GROUNDED WIRES AND PRODUCTION OF HIGH FREQUENCIES IN TRANSMISSION LINES

BY E. E. F. CREIGHTON

ABSTRACT OF PAPER

The overhead grounded wire is used for three purposes: lightning protection, mechanical support for towers, and a test circuit. The functions of the grounded wire are subdivided into at least four categories: First, the vertical grounded wire; second, the lightning rod extending above the ground; third the electrostatic induction in the horizontally situated wires, and fourth, electromagnetic induction.

The vertical wire prevents splitting of the poles. The lightning rod is of mooted desirability. The electrostatic induction for a given cloud on wires under various conditions is worked out in this paper. There is given also the protective values of overhead grounded wires in different positions and in different numbers. The effects of electromagnetic inductions have been taken into account. Theory is given to show that the grounded wire introduces into the main wave of induced lightning surge a superposed high frequency of electromagnetic induction.

The several factors to be taken into account in the process of determining the protective value of a grounded wire are as follows:

1. Strength of electric field in the neighborhood of the line wires.
2. The direction of the gathering charge in the cloud, that is the path of the discharge relative to the line, parallel or perpendicular to the line before it turns vertically downward to the earth.
3. The screening effect obtained by the use of several wires, with and without grounded wires.
4. The initial momentary potential induced on a wire at the instant the cloud discharges to earth.
5. An instant after the lightning discharge has taken place, the sudden increase in capacitance between the power wire and the adjacent parallel grounded wire.
6. The effect of the number and location of parallel grounded wires.
7. The effect of electromagnetic induction between the horizontal part of the grounded wire and the parallel power wires, in which the energy of the lightning charge on the grounded wire is more or less transferred to the power wire, instead of being dissipated in the earth. High frequencies are produced in this transformation.
8. The gradual transference of the charge which travels along the power wire to the successive sections of the grounded wire and its dissipation in the earth.

Manuscript of this paper was received April 8, 1916.

A cloud charge is chosen of such value as to produce corona potential on a No. 000 B. & S. wire, strung at a height of 1000 cm. (33 ft.) above the surface of the earth. This storm cloud is used as a standard in all cases for comparison. The induced voltage on any wire by lightning is directly proportional to the height of the wire above the earth. The induced quantity is not quite proportional due to the variations in the capacitance of the wire at different heights. For heights between 30 and 60 ft. (9.1 and 18.2 m.), however the quantity can be considered as approximately proportional to the height.

The quantity induced on the wire is only slightly affected by the diameter of the wire. This leads to the conclusion that a small grounded wire is nearly as effective as a more expensive large one.

The theory is given to show that even on a non-grounded circuit a charge can be induced by a cloud and produce practically the same potentials as when the circuit is grounded. The only exception is that of circuits of short length.

The instantaneous value of induced potential on a circuit is independent of the number of wires used. Using a greater number of wires reduces the quantity per wire but does not decrease the instantaneous value of the potential at the instant the cloud discharges to earth. Even the grounded wire may take the full potential and give no relief at the first instant. Whether it does or not depends upon how quickly the discharge takes place from cloud to earth, and how frequently along the line the grounded wire is earthed. There is, however, a screening of electrical energy by increasing the number of power wires. In other words, each surge has less energy although it has not initially less potential.

There is given a table of the reduction of quantity per wire as the wires increase in number from one to seven.

The two factors in the electrostatic protection of the overhead grounded wire are screening and increase of capacitance of line wires. The presence of the grounded wire reduces the quantity induced on each of the power wires and incidentally after the cloud discharges to earth the grounded wire takes over part of the charge from the power wires and in taking it the capacitance of each power wire is increased. Therefore, with the same quantity of electricity the potential is reduced by this increase in capacitance.

The protection afforded by one parallel grounded wire can be expressed as a very simple equation. The protection for each power wire can be calculated entirely independent of how many there are.

The general equation to express the protection afforded by two parallel grounded wires is more complex but if the two grounded wires are placed far apart their protective values can, with only a small error, be calculated independently.

As the charge runs to earth on the grounded wire at the instant the cloud discharges, it induces on the line wire by electromagnetic induction a considerable voltage in the usual conditions of the overhead grounded wire with low resistance in the earth connections and from which part of the protection afforded by the grounded wire is lost by the fact that the energy oscillates in the ground circuit and is transferred to the power wire.

The natural frequency of this wave train is found by multiplying 183,000 miles (300,000 km.) per second by the number of earth connections per mile of grounded wire. The frequency is usually over a million cycles per second.

Traveling waves are more or less absorbed as they pass each successive loop of the grounded wire, according to the value of

the resistance of earth connection. In any case an endeavor should be made to have the resistance in the earth connection somewhere near the critical damping value. This prevents initial oscillations in the ground circuit and also increases the rate of absorption of a traveling wave.

A slight amount of high frequency is produced in a circuit by transposition of power wires. This may be of the order of 2 per cent to 5 per cent of the main voltage.

The general deductions for practical use taken from the theory given are as follows: From a theoretical standpoint a single grounded wire should be placed as near as practicable to the power wire in order to get the greatest electrostatic protection. The grounded wires are a little more effective when placed above a power wire than when placed below it.

In installing overhead grounded wires the greatest advantage can be obtained by keeping the overhead grounded wires as far apart as possible, that is to say, installed, as far as practicable on opposite sides of the power wires. The protective value of the second wire will then have its full maximum possible value. Also from the electromagnetic standpoint, the two wires should be placed, so far as practicable, on opposite sides of a power wire in order to reduce to a minimum the transfer of surge energy to the power wire.

The most practicable condition of protection by four grounded wires is to use the four wires in a rectangular formation which gives the widest separation. Naturally two will be above the power wires and the other two will be either below or at each side about on a level with the two lowest power wires. The mechanical conditions of installation will dictate where these wires will be hung and it is necessary to follow the rule to make the distances between the several grounded wires as great as the conditions will permit and still keep the grounded wires as near a power wire as safe mechanical clearance will justify.

I—Introduction

THE OBJECT of this paper is several-fold; primarily it is an endeavor to place the practise of the use of overhead grounded wires on a firmer engineering footing and to discuss the conditions of line construction which cause and suppress high-frequency surges. The desire is to present the material so that the conditions of installation may be made to give the greatest degree of protection with a minimum of undesirable reaction and lowest cost.

In the mathematical analysis there is no so-called higher mathematics. The difficulties involved are due simply to the extremely long simultaneous algebraic equations. It is a matter of labor more than skill. The basis of this analytical work was given by Maxwell, Kelvin and Heavyside and their familiar notation is used. Since most engineers of power systems are too occupied with other problems to juggle involved logarithmic equations, all this analysis is separated from the main body of the paper and is given only as a means of checking up the writer's

conclusions. In most cases the analysis of the value of a grounded wire reduces to very simple formulas, due to the cancellation of many factors in the long, involved equations.

Many operating engineers have noted high potentials across choke coils of low inductance and other phenomena, which point directly to the presence of extremely high frequencies in traveling waves on the line. An endeavor has been made to analyze the possible sources of high frequency. There are at least four of these sources.

The earliest use of the overhead grounded wire is somewhat hidden in obscurity, due to the fact that the engineers of that date were not prolific in writing up their engineering feats. The earliest application of parallel grounded wires that the writer has been able to get track of was made by Mr. C. C. Chesney on the original polyphase transmission plant at Housatonic, Mass. in 1891. It seems that the next plant to use it was the Montreal Light, Heat and Power Co. transmitting power from Shambley Falls to Montreal. The overhead grounded wire gradually found its way into practise by reason of the strong endorsements of a number of engineers, notably among whom was Dr. C. P. Steinmetz. The use of overhead grounded wire was a mooted problem among engineers over a period of many years.

II—Analysis of the Uses of the Overhead Grounded Wire

The first question to settle in discussing the overhead grounded wire is its purpose. Its primary use is of course for protection against lightning and it is recognized also as a strengthening support between towers. Mr. J. Lawson has recently stated that the grounded wire on a wooden pole line is used also as a means of testing for defective insulators. The three recognized uses then are: lightning protection, mechanical support for towers and poles, and a test circuit. The use which is of interest in the following discussion is solely that as a protector against electrical and magnetic disturbances in the surrounding atmosphere.

Even as a protector against lightning the function of the grounded wires may be subdivided into at least four categories: First, the vertical grounding wire, second, a lightning rod extending above the line, third, electrostatic induction in the horizontally situated wires, and fourth, electromagnetic induction.

III—First Category—Protection Against the Splitting of Poles by the Vertical Conductor which at One End Is Buried in the Earth and Runs the Height of the Pole

This part of the grounded wire system has been used from early times in telegraph construction quite independent of the horizontal grounded wire which parallels the power wire, and is still standard practise for telephone and telegraph circuits. Every fifth wooden pole is protected this way. As such, this vertical grounding wire is a protection not against electrostatic induction or electromagnetic induction, but against the damaging effect on wooden poles of a direct bolt of lightning. This vertical grounding wire performs the same function when used in combination with the horizontal wire and at the same time it is an essential part of the horizontal wire in protecting against induction by acting as an earthing contact to the horizontal wire. How frequently along the line these vertical earthing wires should be used is a question of importance to be discussed as the subject is developed.

IV—Second Category—A Lightning Conductor Extending Above the Top of the Pole or Tower Is Designed to Act as an Electrode to the Bolt from the Cloud

The value of this rod lies in the possibility of its greater height keeping the arc flame from being blown between the phases of the power wires, which would cause a short circuit. Used as such, it has nothing to do with the electrostatic induction and functions only in cases of direct stroke on the line. To the writer's knowledge its value has never been definitely determined by calculations, experimentation, or use. Its use has not been very great. The extremely intense electric force and potential gradient in the path of the direct stroke of lightning brings the value of the lightning rod into question. Even if the rod is high enough to keep the ionized flame away from the power wires it must yet be determined if the intensity of electric field, induced on the power wires adjacent to the lower end of this lightning rod, is not great enough to cause a side flash from the rod to the power wires, on account of the so-called isolated capacitance of the power wires. With a power wire supported on an insulator having a grounded metal pin it seems safe to hazard a guess that there will be a side flash which would either

puncture the insulator or cause a flash around the skirts. The puncture distance is of the order of one inch only, and the flash-over distance is of the order of one foot (30.4 cm.) Furthermore, the equivalent sphere gap of this flashover distance, due to the effect known as creepage spark over the surface of the insulator, is only of the order of a few inches at best.

When a wooden cross-arm is used and when the power wires are highly insulated by a string of many suspension disks the chances of side-flash are greatly reduced and consequently the lightning rod comes into the realm where its practicability and use are worthy of consideration and debate.

An endeavor is here made to enumerate the elemental factors involved. There are two conditions to be avoided:

First, to keep conducting arc vapors of the direct lightning stroke away from the power wires.

Second, to prevent a bolt from striking midway between poles. Cases are known where such strokes have melted the wires in two, even where the line was yet under construction and grounded at some distance from the point of the lightning stroke.

Who is to say how far down on the lightning rod the crater of the arc will extend? Taking Dr. C. P. Steinmetz' estimate of 10,000 amperes for the average current in a lightning discharge will the crater, during its brief life, extend below the point of the rod? The heated gases will tend to rise. The heavier the wind the more rapid is the arc flame broken up and cooled. Perhaps some of the many photographs of lightning may throw some light on this problem.

The protection against direct bolts striking the wire between poles may be determined roughly by the following methods: First, for a wire supported on pin-type insulators on wooden poles, the wire may be assumed roughly to follow the arc of a circle, the center of which may be determined. It may be assumed that if the lightning strikes well into this imaginary sector the chances of its turning and reaching the pole are rather remote. Second, if a lightning rod is used or the wires are underhung by suspension insulators, the chances of a lightning stroke reaching the wire rather than the tower or lightning rod are very much lessened. Fig. 1 is drawn on the basis of making the distances from the tip of the tower and the nearest point on the wire equal. The higher the rod or tower above the line, the less the chance of a stroke reaching the line wire, other things being equal. The expression, "other things being equal" is intended

to take into account the fact that a lightning discharge does not necessarily take the shortest path to the nearest object, be it earth or an adjacent cloud. The location of the electric stress depends primarily on the accidental location of condensation of moisture in the atmosphere. Otherwise, if there is no free electricity given off in the atmosphere, the discharge will take place over the shortest path between electrodes.

While this method is admittedly crude, it is the only one available to give a comparison of the immunity of different constructions. By its use some idea can be gained of the advantages of lightning rods and the underhung construction. The evident dangers from a stroke reaching the line is that of burning the wire in two and letting it fall to the ground.

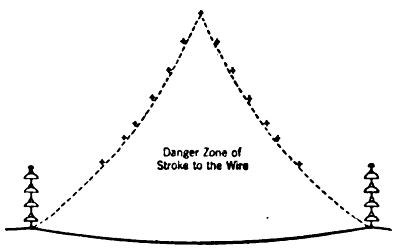


FIG. 1

If lightning gets inside the danger zone shown it is more likely to strike the wire than the tower. The curve is drawn on the basis of equal distances between the insulator and the wire. Direct strokes on the wire may fuse it in two.

With a string of six disks and the midpoint of a 500-foot span of wire 30 feet below the top of the tower the peak of the sector is 1050 feet above the midpoint of the span. With a pin-type insulator, a span of 100 feet and a sag of 2 feet, the peak of the sector is 650 feet above the midpoint of the span of wire. A 6-foot lightning rod added to the latter case lowers the peak of the sector to 160 feet and bands inward as shown in the above figure.

Should a lightning rod be sharp pointed? The early work done by Dr. Steinmetz on corona of needle points and later the work of Mr. F. W. Peek and others on corona would seem to indicate that the sharp end would have no particular value. Induced potentials of corona value often occur during storms. The formation of corona gives immediately the equivalent of a blunt end. The relief of the atmosphere by the discharge of corona is apparently too local and of such a small part of the volume of the electrostatic field of the atmosphere above the line to decrease appreciably the energy of a lightning stroke.

These questions are still in the speculative field and must be left, as refinements, to be cleared up by later work. The rest of the subject is of more importance at present and a solution is more definitely in sight.

V—General Problems of the Parallel Grounded Wire

There are several factors to be taken into account in the process of determining the protective value of the grounded wire.

1. Strength of electric field in the neighborhood of the line wires.

2. The direction of the gathering charge in the cloud, that is, the path of the discharge relative to the line, parallel or perpendicular to the line before it turns vertically downward to the earth.

3. The screening effect obtained by the use of several wires, with and without grounded wires.

4. The initial momentary potential induced on a wire at the instant the cloud discharges to earth.

5. An instant after the lightning discharge has taken place, the sudden increase in capacitance between the power wire and the adjacent parallel grounded wire.

6. The effect of the number and location of parallel grounded wires.

7. The effect of electromagnetic induction between the horizontal part of the grounded wire and the parallel power wires, in which the energy of the lightning charge on the grounded wire is more or less transferred to the power wire, instead of being dissipated in the earth. High frequencies are produced in this transformation.

8. The gradual transference of the charge which travels along the power wire to the successive sections of the grounded wire and its dissipation in the earth.

VI—Getting a Reasonable Mathematical Cloud

In the mathematical analysis of the electrostatic phenomena only the simplest forms,—such as cylinders, spheres, ellipses,—lend themselves to a practicable solution. The limitless variations in the forms of storm clouds make it impossible to select a form which might be considered the average for a thundercloud. Therefore it is necessary to turn from the cloud to the local electric field near the earth which is, after all, the center of interest. At the surface of the earth all forms of clouds give one common characteristic, namely a fairly uniform, perpendicular directed electric force over a limited area. It is assumed at present that the surface of the earth is smooth. In making the mathematical analysis we are, therefore, privileged to choose any form of cloud that gives this uniformity of field near the earth. Since we are to study first the electrostatic induction on overhead wires it is natural to choose, as a matter of simplification, a cylindrical cloud parallel to the line. In the early study, lengths of wire only one centimeter long will be dealt with and

therefore over many centimeters any sort of a cloud can be considered cylindrical.

In any cylindrical conductor from which a charge of electricity emanates there is a central point where all the lines of force would meet if they were extended everywhere through the surface of the cylinder. Mathematically th is point is well-known as the inverse point of a circle. Electrically it is better described as the apex of charge. The apex of charge is that point which, if all the charge were concentrated there, would give the same effect as it does distributed over the surface.

It is recognized that a cloud is not a good conductor but due to its mobility to the movement of electricity by brush discharge it is assumed that the cloud will act like a cylinder of equal dimensions. Since this does not affect the distribution of field near the surface of the earth it seems a permissible assumption to make and is a great convenience in making calculations. (Fig. 2)

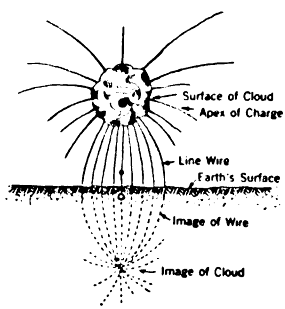


FIG. 2
Cloud of cylindrical cross-section, its electric field, its image, and a line wire in the field.

The apex of charge of the cloud will be found and calculations will be made assuming that the charge of the cloud is concentrated along this apex of charge as if it were a conducting wire parallel to the line wires.

VII—CHOICE OF THE HEIGHT OF A CLOUD

In absolute measure, the first effect of an increase in the height of a cloud would tend to decrease the electric force, and consequently electric induction, on overhead wires. An increase in the total charge on the cloud increases the quantity induced on the line wires. All we can say at present is that actual clouds will cause more or less severe induction on the overhead wires and let it rest at that. The object we have in view is to choose a height and dimensions of a cloud such as to give a uniform field in the neighborhood of the power wires. If the apex of the cloud is a few times as high as the line wires it is found sufficient. A height of 55,000 cm. is chosen, however, for the position of the apex of the charge of the cloud. This value will be retained as a standard of reference for all future calculations.

VIII—Choice of a Given Charge on a Cloud for Use in Making Comparative Calculations of Protection Which May Be Expeced from Parallel Grounded Wires—and Other Data

A reasonable cloud charge is chosen arbitrarily as one which will induce a charge on a single overhead wire of corona intensity. It is found that such a cloud charge with its apex at 55,000 cm. height can be made to give very mild intensities of charge or potential gradients in the cloud itself, and such a cloud seems satisfactory enough as a basis of comparing induced charges on line wires.

All calculations are made in the absolute system of units. Anomalously, the practical system is impracticable.

An overhead wire of a usual radius of 0.5 cm. (about 3/8 in. in diameter, approximately No. 000 B. & S.) will have a critical corona gradient of potential at its surface when the charge is about 25 statcoulombs per centimeter length of wire (0.001342 coulomb per mile.*) Placing this wire at a height of 1000 cm. above the surface of the earth calls for a charge of 5700 statcoulombs per centimeter length of the assumed cylindrical cloud, to bring the grounded wire to the condition of corona. In all future calculations this constant cloud charge will be used.

One other assumed dimension is made, namely 10,000 cm. from the apex of charge in the cloud to the lower surface of the cloud. The assumed and calculated factors are given in the following list:

Apex of charge of the cloud, 55,000 cm. (1804 ft.) above earth.

Radial distance apex to surfaces, 10,000 cm. (328 ft.)

Height of wire used as standard of comparison, 1000 cm. above the surface of the earth (33 ft.)

Quantity of electricity induced on this line wire, 25 statcoulombs per centimeter length of wire (0.001342 coulomb per mile).

Quantity of electricity in the cloud, 5700 statcoulombs per centimeter length of the cylindrical cloud (0.306 coulomb per mile).

Potential at the surface of the cloud, 26,224 statvolts (7,867,200 volts).

Potential gradient at the lower surface of the cloud, 1.254 statvolts per centimeter of vertical distance (376.2 volts per centimeter). The gradient to produce corona is nearly 100 times as great, *i. e.* 30,000 volts per centimeter. Expressed in inches and feet, the potential gradient is 956 volts per inch and 11,472 volts per ft.

The field intensity at the surface of the earth is 0.4147 dyne, and correspondingly the potential gradient is 0.4147 statvolts per centimeter. (124.4 volts per centimeter = 3800 volts per ft.)

---

*$f = \frac{2q}{r} \quad q = \frac{fr}{2} = \frac{100 \times 1/2}{2} = 25$

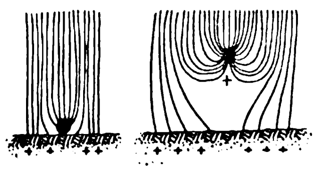
Dielectric displacement at the surface of the cloud is 0.1 statcoulomb per square centimeter of cross-section of the field.

Dielectric displacement at the surface of the earth directly under the cloud is 0.033 statcoulomb per square centimeter of earth surface.

NOTE: The undisturbed field intensity, potential gradient, and dielectric displacement at a height above the surface of the earth corresponding to line wire heights are sensibly the same as the values given above for the surface of the earth. Therefore, over the range of height corresponding to the usual height of a line wire the potential may be obtained, theroetically, by calculating the product of the height and potential gradient (V = centimeter height × 0.4147). The general relations are shown in Fig. 2. The calculations are made by equations (**1**) and (**2**) in the mathematical section.

IX—THE INDUCED CHARGE ON A SINGLE WIRE AT VARIOUS HEIGHTS FROM THE EARTH

The value of induced charge, initally at zero potential, is the second step in the determination of the voltage on the line which will suddenly appear when the cloud discharges to earth and sets free the bound charge on the line. We have just noted in the previous paragraph that the inducing potential is proportional to the height above the earth. The induced quantity at increasing heights does not, however, follow in direct proportion due to the change in capacitance of the wire.



FIGS. 3 and 4

Illustration of the cross-section of the electric field in the neighborhood of a wire, Fig. 3 on the ground and Fig. 4 in the air. The latter gathers in the field from each side nearly in proportion to its height.

Above a height of 1000 cm. (33 ft.) the increase in the quantity of electricity induced is almost a linear relation to the height of the line. This law holds up to and somewhat beyond 4000 cm. At less heights than 100 cm. the charge falls off more rapidly on a slightly curved line. The actual relations are shown in the curve of Fig. 3. These quantities are obtained by a solution of equation.

$$V_1 = 0 = \left(4.6 \log_{10} \frac{m_{11}}{r_1} \right) q_1 - \left(4.6 \log_{10} \frac{m_{c1}}{r_{c1}} \right) q_c$$

Whence—

$$q_1 = \left(\log_{10} \frac{m_{c1}}{r_{c1}} \frac{r_1}{m_{11}} \right) q_c$$

At 1000 cm. high, we have assumed a charge of 25 statcoulombs per centimeter length of the wire. At 2000 cm. high the induction would be 46.4 statcoulombs per centimeter length of wire, using the same inducing charge in the storm cloud. At 4000 cm. high, the wire would have induced on it 85.7 statcoulombs per centimeter length of it. Fourteen different heights are given in Table I, which also gives the quantity on the wire as a fraction of the total charge in the cloud. For example, at 1000 cm., the charge on the wire is 0.00439 part of the charge in the cloud.

There is given also in the table the total width of electric field that is gathered in by the wire. For example, the wire at 1000 cm. (33 ft.) gathers in the field from each side for a distance of 379 cm. (12.4 ft.), making a total width of 758 cm. (24.9 ft.). This electric field would normally go straight to the earth but due to the presence of the grounded wire is drawn toward the wire and a large part of it passes through the horizontal plane of the wire and is looped back up as is shown in Fig. 4.

At a height of 2000 cm. (65.6 ft.) the overhead grounded wire draws a field in from each side from a distance of 704 cm. (23.1 ft.).

A more satisfactory analysis of what takes place when a grounded wire is raised to different heights above the earth is shown in the two sketches, Figs. 3 and 4, which depict values taken from the table.

If a bare wire is lying on the ground (Fig. 3), it will take an electric charge which is proportional to about half its superficial area. The earth itself has a charge of 0.033 statcoulomb per square centimeter due to the charge of the cloud. Therefore, the charge on the wire lying on the ground will be of this order. When the wire is raised off the surface of the earth, as is shown in Fig. 4, a few of the lines near the wire which before found an easier path to the earth, now find a shorter path by bending around to the wire. The lines of force just beyond this width find a more desirable path to the ground than to the wire but due to the removal of part of the electric field directly underneath the wire these lines are bent under the wire in their path to earth.

The width of field drawn into the wire is obtained by dividing the charge emanating from the wire by the number of statcoulombs of displacement per square centimeter, due to the cloud.

Table I gives the heights of wire, fraction of the cloud charge which ends on the wire, quantity statcoulombs per centimeter

length of wire, percentage of same referred to a wire at 1000 cm. height, the width of the field drawn into the wire at the height given, atmospheric quantity is 0.033 statcoulombs per centimeter and the potential gradient is 0.4147 statvolt per centimeter.

TABLE I.

Height of wire dia. 1 cm.	Part of cloud charge on wire	Stat-coulombs quantity per cm. length of wire	Per cent of quantity at height of wire of 1000 cm.	Width of field picked up by wire, cm.	Atmospheric potential at height given	
					Statvolts	Kilovolts
100 cm.	0.000633	3.610	14.4	119.5	41.47	12.44
200 cm.	0.001085	6.180	24.7	187.5	82.94	24.882
400 cm.	0.00196	11.164	44.6	338.8	165.88	49.764
800 cm.	0.00360	20.535	82.1	623.0	331.76	99.528
1000 cm.	0.00438	25.000	100.	758	414.7	124.4
1100 cm.	0.00476	27.170	108.7	824	456.17	136.85
1200 cm.	0.00514	29.277	117.1	888.	497.64	149.29
1600 cm.	0.00663	37.821	151.3	1148	663.52	199.056
2000 cm.	0.00815	46.422	185.7	1410	829.4	248.82
2400 cm.	0.00950	54.169	216.7	1642	995.28	298.58
2800 cm.	0.01090	62.200	248.8	1887	1161.16	348.348
3200 cm.	0.01235	70.516	282.1	2140	1327.04	398.112
3600 cm.	0.01370	78.092	312.4	2370	1492.92	447.876
4000 cm.	0.01502	85.668	342.7	2600	1658.8	497.64

X—The Induced Charge on a Single Overhead Wire as Affected by Its Size

As a convenient size for reference a diameter of one cm. for the overhead wire has been chosen and on this is induced 25 statcoulombs per centimeter length of wire (0.001342 coulomb per mile).

The first step will be to reduce the size of wire. As a rough approximation, take one strand of a seven-stranded cable and let us assume an equivalent diameter of one-third which is a radius of 1/6 cm. This wire will have induced on it by the storm cloud 22.1 statcoulombs which is 88 per cent of the quantity induced on the wire of one cm. diameter. The reduction then in the weight of the wire approximately to 1/7 has reduced the quantity of electricity drawn in by the overhead grounded wire by only 12 per cent. This is a good illustration of the slight effect that the size of the overhead wire has in gathering in the electric field. The same statement is true for sizes of wire larger than the one of diameter of one cm. If the weight of the wire is

increased four times, that is to say, with an increase in the diameter from one cm. to two cm. the quantity of electricity terminating on the wire increases only 10 per cent. If the weight of the wire is increased sixteen times, which corresponds to an increase in the diameter from one cm. to 4 cm., the quantity of electricity terminating on this wire from the same storm cloud will be only 20 per cent greater if the weight of the wire is increased 64 times, which corresponds to an increase in the diameter from one cm. to eight cm., the quantity of electricity terminating on this wire will be only 33.6 per cent greater.

We may conclude from these data that calculations of electrostatic induction made for a wire of 0.5 cm. radius will give approximations for all other wires of usual practise.

INDUCING A CHARGE ON AN OVERHEAD WIRE WHICH IS NOT GROUNDED

From experiences in the laboratory in electrostatic induction such as the electrophorus, where it is necessary to ground the metal plate while it is near the charged wax plate in order to get it to take a charge, it is sometimes erroneously assumed that it is necessary to have an overhead wire grounded somewhere in order likewise to get it to take a charge from cloud induction. Contrary to this assumption, it may be stated that, in general, a system with a non-grounded neutral and absolutely no leakage over the insulators charges up with about the same quantity under the storm cloud as a system with a grounded neutral. The exceptional case is the short length of circuit.

Laboratory experience may give inadequate conceptions of the conditions outdoors and the local characteristic of a cloud lightning. It is not a question of how many square miles the storm cloud covers but only what extent of electrostatic field between cloud and earth is relieved by the lightning stroke. We are accustomed to seeing the visible part of the streak a mile or so long only. If the streak in the cloud is parallel to the transmission line relief over a corresponding length is given to the charge induced on the line wires. But the transmission wires extend miles beyond this influence and it is the capacitance of wire to ground in the extended lengths not directly under the influence of the storm cloud which allows a non-grounded wire to take an induced charge.

Fig. 5 shows a short length of wire not extending beyond the field of the cloud. The wire takes the potential of the air at

the same height. The corresponding d-c. stress is thrown on the insulation of the apparatus until the lightning stroke takes place. After the lightning stroke there is no charge on the line, and the potential of the line wire returns to normal without the presence of the usual traveling waves. For the traveling wave there has been substituted a d-c. stress over a period of time depending on the rapidity of formation of the storm cloud. Leakage over the insulators will enter, of course, to give the line more or less of a charge.

Now turning to the more usual condition of a non-grounded circuit, Fig. 6 shows how the cloud induces a charge under it without leakage to ground. The large part of the line not under the cloud acts as a condenser of large capacitance which absorbs

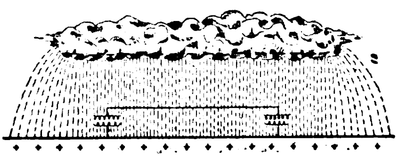


FIG. 5

Illustration of a short line under a long cloud. This line can become charged by leakage to ground only.

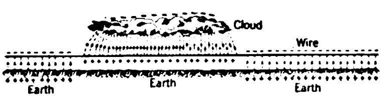


FIG. 6

Illustration of a long line under a short cloud. This line can become charged without any leakage of current to ground, that is to say, without any grounding.

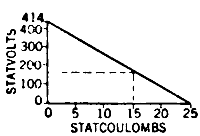


FIG. 7

The relations between induced quantity and potential on a non-grounded line wire. [000 B. & S. wire, 1000 cm. (33 ft.) high and a field of 0.414 statvolt per cm. (potential gradient.)]

the relatively small quantity induced by the cloud without causing much rise in line potential. [$V = Q \div C$] The relations between the induced quantity and potential on the line wire are somewhat unusual. When the quantity is zero the induced potential (by the assumed cloud) is 414.7 statvolts. On the other hand, when the potential is zero, that is to say, the wire is grounded, the quantity is 25 statcoulombs. The intermediate conditions are shown by the straight line in Fig. 7.

$$V + 16.6q = 414.7$$

For different relative lengths of line under and not under the cloud the following conditions hold: If there is one mile under the cloud and nine miles of line not under, the potential of the

wire will be 41.47 statvolts, $[1 \div (9 + 1)]414.7$. The quantity will then be $0.9 \times 25 = 22.5$ statcoulombs.

If, again, the relative lengths are two miles and 98 miles, the induced potential will be 2 per cent of $414.7 = 8.3$ statvolts and the induced quantity will be 98 per cent of $25 = 24.5$ statcoulombs.

Now, when the cloud discharge takes place there are two traveling waves, namely, the wave due to the concentrated charge under the cloud, and the wave due to the distributed charge throughout the rest of line and coils of the apparatus. These waves move in opposite directions and, since they are of opposite signs of electricity, as the concentrated wave passes through the distributed wave it will lose its potential in proportion to the cancellation of quantity.

It should be noted that the distributed charge has a quantity located down in the coils of generators and transformers depend-

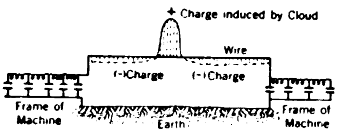


FIG. 8

The shaded parts on the overhead line shows the location of the two separated charges. The coils and condensers at the end of the line represent the conditions in a generator or transformer. Each coil is charged as a condenser by the lightning cloud.

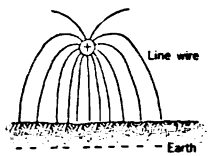


FIG. 9

The field of the induced charge on a line wire at the instant after the storm cloud discharges to earth.

ing on the local capacitance of the coils to the earth. After the cloud discharge, this lightning is inside the apparatus and must get out. In so doing it must bump into the inductance of each adjacent coil and be reflected more or less. Incidentally, this is a source of high frequency oscillations. An attempt is made to represent these conditions in Fig. 8.

FUNDAMENTAL LAW OF INSTANTANEOUS POTENTIAL AND QUANTITY IN CASES OF INDUCTION

It is purposed to show the simple method of obtaining the potential after the lightning discharge has turned free the previously bound charge on the line. To do this the movement of electricity in the cloud at the beginning and during the discharge of the lightning will not be considered now, but will be the subject of a later paragraph. As a further simplification the wire will be assumed grounded through either a resistance

or inductance, so that its potential may be considered zero during the period of electrostatic induction.

At 1000 cm. up from the surface of the earth, the chosen cloud produces 414.7 statvolts (124,410 volts). A grounded No. 000 wire (one cm. diameter) at this height will take a charge of 25 statcoulombs by electrostatic induction. When the cloud discharges, the field which extends between wire and cloud will suddenly flop over (with more or less oscillation according to the nature of the lightning bolt) and appear as a field between wire and ground. The bound charge has been shown already in Fig. 4. The freed charge is shown in Fig. 9.

The potential will be given by the equation $V = Q \div C$ where Q is the quantity per unit length and C is the corresponding capacitance between wire and ground per unit length.

The object of this paragraph is to point out that to obtain the final potential rise of the wire it is unnecessary to calculate either the induced quantity or the capacitance of the wire. The potential of the wire immediately after the cloud discharge is the same as existed at this height with no wire present, namely 414.7 statvolts (124,410 volts).

This is a fundamental law and applies equally well to any number of overhead wires. It will be shown later that the addition of every wire on a pole reduces the quantity of electricity induced on each wire but it does not reduce the instantaneous potential of the freed charge. If a second wire is placed at a height of 1100 cm. (100 cm. above the first wire) the instantaneous potential after the lightning discharge is found by multiplying the undisturbed potential gradient in the atmosphere by the height of the wire; thus, 1100 cm. $\times$ 0.4146 statvolts per centimeter gives 456 statvolts (136,800 volts). The first wire again assumes a potential of 414.7 statvolts.

SCREENING OF ENERGY INDUCED BY THE USE OF SEVERAL PARALLEL WIRES ON THE SAME POLE

It has just been stated in a fundamental law that the presence of several wires does not decrease the instantaneous potential at cloud discharge although there is a decrease in quantity per wire due to the presence of several wires. (Nothing is being said at present of grounded wires.) The several wires produce a screening of quantity without a useful effect on the resultant instantaneously induced potential. There is, however, a useful screening effect of energy in the surge.

For example, with one wire alone the induced quantity is 25 statcoulombs per centimeter length of wire. The instantaneous potential of the electric wave is 414.7 statvolts and the instantaneous electrostatic energy is 5180 statjoules or ergs per centimeter. Placing a second wire of the same diameter and at the same height but spaced 100 centimeters reduces the quantity on the first wire from 25 statcoulombs to 18.36 statcoulombs per centimeter. The energy is thereby reduced to a corresponding amount (73.4 per cent), that is, to 3805 statjoules per centimeter. There is less energy in the wave on each wire to be dissipated. However, the total quantity is increased from 25 to 36.72 statcoulombs per centimeter and the total energy from 5180 to 7610 statjoules. The quantity and energy are equally divided between the two

1 one wire (overhead). Electric field constant.
q=25 statcoulombs on a No. 000 wire

	1	2					
q=18.36	18.36		Quantity total=36.7				
	3	1	2				
q=15.70	13.65	15.70		Total=45, Average=15			
	5	3	1	2	4		
q=13.4	10.6	9.94	10.6	13.4	Total=57.94, Av.=11.59		
	7	5	3	1	2	4	6
q=12.42	9.44	8.21	8.09	8.21	9.44	12.42	

Total=68.23, – Av.=9.75

FIG. 10

Induced charges on line wires by a constant electric field. Wires are No. 000 and spaced 100 cm. (39.4 in.) horizontally. Five groups separately, each group 1000 cm. (33 ft.) above the surface of the earth. Groups; 1 wire, 2 wires, 3 wires, 5 wires, and 7 wires. All quantities are given in statcoulombs per cm. length of wire.

parallel wires because they are the same size and at the same height.

In conclusion: Increasing the number of parallel wires decreases the energy in the surge per wire without decreasing the initial instantaneous potential. The closer the wires to each other, the greater the reduction in energy. As a limit, the reduction in energy, even if the wires are so close as to touch is a little less than inversely proportional to the number of wires. For example, two wires cannot reduce the energy to quite half of what would be induced on one. At the other extreme, when parallel wires are far enough apart to be outside each others fields they exert no screening effect on each other.

The numerical values above are calculated by equations (**5**), (**6**), (**7**), (**8**), and (**9**) (mathematical section). The general equations are given in equations (**12**) and (**13**).

For No. 000 wires in a horizontal plane, 100 cm. spacing, the quantities induced are given in the following list. The central wire is always numbered 1, and the even numbers are assigned to the right and symmetrically placed wires to the left are assigned the next odd number, thus, (3) (1) (2)...

Wire one only $q_1 = 25$ statcoulombs per centimeter length of wire. Two wires $q_1 = q_2 = 18.36$.

The last diagram with four wires grouped around one wire shows an average reduction in quantity from 25 to 10.8 statcoulombs per centimeter which gives a reduction in surge energy to 43 per cent average per wire, other lightning conditions being equal. The equations for this group are (**14**,) (**15**), (**16**) and (**17**) in the mathematical section.

Height
(1) 1000 cm.
$q_1 = 25$

(2) 1100 cm., $q_2 = 20.9$
(1) 1000 cm., $q_1 = 17.3$
Total = 38.2
Av. = 19.1

(1) 1000 cm., $q_1 = 19.4$
(3) 900 cm., $q_3 = 15.8$
Total 35.2
Av. 17.6

(2) 1100 cm., $q_2 = 18.8$
(1) 1000 cm., $q_1 = 13.6$
(3) 900 cm., $q_3 = 12.6$
Total 45.
Av. 15.

(2) 1100 cm.
14.41 statcoulombs
(5) (1) (4)
11.45 8.45 11.45
(3) 900 cm.
8.4

FIG. 11

Induced charges on line wires by a constant electric field. The five groups are to be considered separately. Size of wire No. 000, spacing 100 cm. Quantities induced at the given heights as given above. All quantities are given in statcoulombs per cm. length of wire.

USE OF A PARALLEL GROUNDED WIRE. SCREENING AND INCREASE OF CAPACITANCE OF LINE WIRES

The grounded wire produces no more screening effect than a power wire in its place. Also it does not, at the first instant of cloud discharge, reduce the potential induced on a power wire, except at the pole where the vertical riser from ground is connected to the parallel ground wire. If the lightning stroke were absolutely instantaneous, the parallel grounded wire would rise to the potential it would have if it were not grounded. Since the lightning bolt requires time to form, some of the quantity set free on the parallel grounded wire will have time to pass down the vertical connection to ground and immediately be-

comes the seat of a charge induced by the charge on an adjacent parallel power wire.

The three stages are shown in Fig. 12.

The grounded wire increases the capacitance of the power wire and thereby reduces its potential without in any way reducing its charge. The capacitance to earth of the one wire alone at 1000 cm. height is 0.0603 statfarad per centimeter (10.78 millimicrofarads per mile). The capacitance of the same wire to the combined surface of the earth and the parallel grounded wire, 100 cm. separation, is 0.0693 statfarad per centimeter. Therefore, the reduction in potential due to increase of capacitance alone should be to 87 per cent. The quantity, by screening, was reduced from 25 to 18.3 statcoulombs (73.4 per cent). The total reduction in potential will be the product 87 per cent × 73.4 per cent = 63.8 per cent. Subtracting this from 100 per cent gives 36.2 per cent, a factor which may be called the protection afforded by the ground wire. In other words, it means that with a given cloud and no parallel grounded wire the potential of a power wire would rise instantaneously to 414.7 statvolts but with the ground wire in place the same cloud discharge will cause a rise of only 264.7 statvolts. This is a voltage ratio of 63.8 per cent, or a protection of 36.2 per cent of the potential which would have existed without the guard wire.

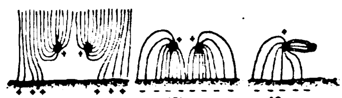


FIG. 12

Showing three stages of charge on one power wire and one parallel grounded wire (the right one). 12-a is the condition of induction before the cloud discharges to earth (not to the line), 12-b is the condition at the instant the cloud is discharged. 12-c. is the condition as soon as the charge on the grounded wire can pass to earth. The ground wire then takes an induced charge from the power wire and thereby increases the latter's capacitance.

PROTECTION AFFORDED BY ONE PARALLEL GROUNDED WIRE

In the previous work two steps were taken in the calculations simply to show the two theoretical factors involved, namely screening and increased capacitance. By treating the equations symbolically most of the factors cancel out in the two steps, leaving a very simple formula which gives the protection in one calculation.

Taking first the case of two wires in a horizontal plane, one a grounded wire, the

$$\frac{\text{Potential protected}}{\text{Potential unprotected}} = \frac{a - b}{a}$$

$$\text{where } a = 4.6 \log_{10} \left(\frac{2 \times \text{height}}{\text{radius of grounded wire}} \right)$$

$$b = 4.6 \log_{10} \left(\frac{\sqrt{(2 \text{ height})^2 + (\text{spacing})^2}}{\text{spacing}} \right)$$

$$\text{and the protection } = \frac{b}{a}$$

The symbolic solution is shown in equations (**18**) to (**27**) inclusive.

The equation shows that the protection decreases as the distance between the wires in the horizontal plane increases in accordance with the logarithm of a ratio. For a No. 000 wire one cm. in diameter and 1000 cm. (33 ft.) high, the factor a = 16.6. Various values of b are given as follows: For 50 cm. (19.7 in.) spacing from the grounded wire the factor b = 7.38 and the protection is 44.5 per cent. For 100 cm. (39.4 in.) spacing, b = 6, and the protection is 36.3 per cent. For 200 cm. (78.7 in. spacing, b = 4.6 and the protection has fallen to 27.7 per cent. At 500 cm. (197 in.) spacing, half the height, b = 2.83 and the protection is 17 per cent. Lastly at a spacing equal to the height, viz. 1000 cm. (33 ft.), b = 1.61 and the protection is 9.7 per cent.

The protection is entirely independent of the size of the power wire. This is due to the fact that as the power wire is increased in size it has induced on it a greater quantity, but this is compensated by an equally greater capacitance to the earth and grounded wire. This is proven mathematically in the symbolical equations (**18**) to (**28**).

There is another simple relation. So long as there is but one grounded wire, the equation just given applies individually to any number of wires in a horizontal plane. Each calculation is made quite independently. The equation does not apply for two or more parallel grounded wires.

PROTECTION OF WIRES STRUNG IN A VERTICAL PLANE

The protection of a parallel grounded wire increases in direct proportion to its height relative to the power wire under consideration. For example, if the power wire (No. 2) is hung 100 cm. (39.4 in.) under the grounded wire, then due to the height alone the protection will be increased by the ratio of height,

1000 cm. $\div$ 900 cm. = 1.11. The factor designated by the symbol b will also change somewhat.

$$b' = 4.6 \log_{10} \left(\frac{2 \times \text{height of grounded wire}) - \text{spacing}}{\text{spacing}} \right)$$

This equation applies when the grounded wire is above the power wire. If the contrary condition is true, then the spacing given in the numerator is to be added instead of subtracted.

$$\text{Protection} = \frac{b'}{a} \frac{h_1}{h_2}$$

When h_1 is the height of the grounded wire and h_2 the height of any power wire strung in the vertical plane.

Examples: Parallel grounded wire No. 000 (one cm. diameter) at a height of 1000 cm. (33 ft.). Power wire, of any diameter, at 900 cm. directly underneath, $b^1 = 5.89$ and the

$$\text{protection} = \frac{5.89}{16.6} \frac{1000}{900} = 0.355 \times 1.111 = 39.4 \text{ per cent.}$$

With the power wire directly above the grounded wire $b' = 6.085$ and the

$$\text{protection} = \frac{6.085}{16.6} \frac{1000}{1100} = 0.367 \times 0.91 = 33.4 \text{ per cent.}$$

Exchanging positions of the power wire and grounded wire $a = 16.78$, $b' = 6.085$, and the

$$\text{protection} = \frac{6.085}{16.78} \frac{1100}{1000} = 0.363 \times 1.1 = 39.9$$

Now keeping the grounded wire above, raise the power wire to double the height, viz. 2000 cm. (66 ft.) and double the spacing to 200 cm. (78.7 in.), the factor $a = 18$, $b' = 5.89$ again, and the

$$\text{protection} = \frac{5.89}{18} \frac{2000}{1800} = 0.327 \times 1.111 = 36.3 \text{ per cent.}$$

For a second power wire hung 200 cm. (78.7 in.— under the first power wire, $b' = 4.4$, and

$$\text{protection} = \frac{4.4}{18}\,\frac{2000}{1600} = 0.244 \times 1.25 = 30.5 \text{ per cent.}$$

For the third phase wire hung 200 cm. (78.7 in.) below the second wire, $b' = 3.47$ and the

$$\text{protection} = \frac{3.47}{18}\,\frac{2000}{1200} = 0.1928 \times 1.667 = 32.1 \text{ per cent.}$$

Attention is drawn to the greater protection given to the lower wire as compared to the one just above it. There are two factors involved which are antagonistic. First, the protection decreases as the distance from the grounded wire to the power wire beneath is increased. Second, the protection is increased as the power wire is lower, due to the ratio of the heights.

The foregoing figures are approximately the same as obtained in the usual practise. A grounded wire $\frac{3}{8}$ in. in diameter is not much less than one cm. Towers are about 60 ft. high and spacings about six ft. Only one parallel grounded wire is usual even with two power circuits. The number of power wires has no effect on the protection against potential but, as shown previously, decreases the energy in the surge on each wire.

The single grounded wire is not usually directly over the three-phase circuit but this makes relatively little difference in the results. To give the factor b for wires in a horizontal plane and b' for wires in a vertical plane a general value needs only the use of the well-known equation for the coefficient of quantity, thus

$$b_1 = 4.6 \log_{10} \frac{m_{21}}{r_{21}}$$

where m_{21} is the distance of the image of the power wire to the ground wire and r_{21} is the spacing between the wires.

The laws for obtaining the best protection possible with a single grounded wire expressed in a practical form are: (1) string the power wires as near the earth as practicable; (2) string the grounded wire above but as near to the upper power wire as safe mechanical spacing permits.

PROTECTION AFFORDED BY TWO PARALLEL GROUNDED WIRES

It may be said immediately, without mathematical analysis, that the degree of protection afforded by two grounded wires depends on where the two wires are placed relative to each other. If they should, in the one extreme, be placed side by side, the added protection by the second wire would be very slight. If, on the other hand, they are placed on the opposite sides of a power wire their protection together is nearly as great as the values calculated separately and then combined.

The protection given by two grounded wires with one power wire anywhere between them, and all wires situated in the same horizontal plane is

$$\text{protection} = \frac{b + f}{c + d}$$

where the coefficients b, f, c and d are given by equations (**38**), (**39**), (**40**), and (**41**) respectively.

For example, wires No. 000, one cm. diameter, height = 1000 cm. (33 ft.) and spacing 100 cm. The central wire No. 1 is the power wire. Its coefficient a is not involved because the protection is independent of the size of the power wire. Coefficient $b = f = 6$, $c = 16.6$, and $d = 4.6$

$$\text{Protection} = \frac{6 + 6}{16.6 + 4.6} = \frac{12}{21.2} = 56.8 \text{ per cent.}$$

The potential ratio = 1 − 56.8 per cent = 43.2 per cent.

The potential ratio of one grounded wire and one power wire, previously calculated, was 63.7 per cent. Assuming, somewhat erroneously, that the real value combined is the product of the separate values, gives 63.7 × 63.7 = 40.6 per cent. This is 2.6 per cent too small but roughly approximate.

If the two grounded wires are not on opposite sides of the power wire the error of such an assumption will be materially greater.

Before pursuing further the value of the use of several parallel grounded wires it is desirable first to consider other fundamental relations in connection with electromagnetic induction which must be taken into account in deciding on the location of multiple grounded wires.

THE REACTION FROM THE LOOP OF THE GROUNDED WIRE BOTH ELECTROSTATIC AND ELECTROMAGNETIC

So far it has been assumed that the charge on the overhead wire at the instant of release by the cloud discharging to earth, passes harmlessly to earth without attending phenomena of interest. This is true, it would seem, only under exceptional conditions. This freed electric charge represents a definite energy. This energy must be either dissipated or transferred to some other circuit, since there is no way of preserving it intact in the grounded wire loop either as electrostatic or electromagnetic energy.

Each loop forms a distributed capacitance and double return circuit, Fig. 13, and shown in equivalent circuit in Fig. 14. Unless the ohmic resistance in the loop is equal to or greater than the critical damping resistance an oscillation will follow the initial discharge to earth of the freed charge. As a matter of fact, the resistance, especially of metal towers, is but of small

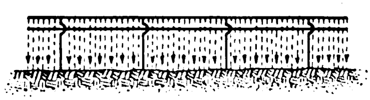


FIG. 13
Distributed charge and loop circuit to ground of a grounded wire at the instant its induced charge is freed.

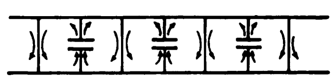


FIG. 14
The equivalent circuit and the discharge of a grounded loop.

fraction of the critical damping value. Many oscillations will therefore take place.

So much for the charge induced by the cloud. The same statements apply to the charge induced on the parallel grounded wire by the charge on the power wire as shown in Fig. 12. C.

The value of this induced charge, already calculated for a steady condition, will overshoot Fig. 15. Momentarily it is possible to get nearly double the steady value.

For the present, the assumption is made that the length of line wire is no greater than the length of the inducing cloud. This is done for the sake of simplicity. It avoids the consideration of the traveling wave. On this assumption the charge which is freed on the power wire remains stationary except for local disturbances which come from the discharge of the grounded wire to earth.

Due to the electrostatic effect alone, the surge potential on the power wire drops from its initial value and oscillates across its

final value. For example, for the two wires at 100 cm. separation both in the same horizontal plane and one grounded, the potential drops on the power wire from + 414.7 statvolts to + 195 statvolts and only after several oscillations does it reach its final stationary value of +264 statvolts. This oscillation takes place while the oscillation in Fig. 15 is active.

The electromagnetic effects must also be considered. The surges in the grounded wire are free to move with a velocity nearly equal to that of light. A considerable value of current will be reached. Rings of magnetism emanating from the grounded wire cut the parallel power wire and induce therein electromotive forces which are proportional to the mutual inductance between the power wire and grounded wire, and to the rate of change of current, $e = M\frac{di}{dt}$.

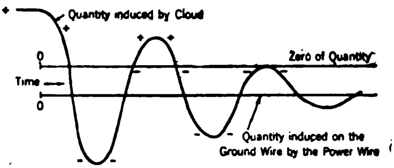


FIG. 15

The oscillation of the quantity on the grounded wire from the steady positive value at the instant it was released by the cloud discharge to the later negative value induced by the adjacent positively charged power wire.

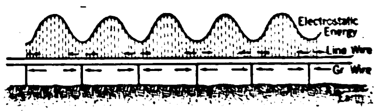


FIG. 16

The grounded wire loop is shown below the power wire. Currents are represented by arrows. The resulting humps in the electrostatic energy are depicted above the power wire.

The surge current in the parallel grounded wire will rise to its greatest value at the pole or tower where it is connected to ground by the vertical riser. The current will be zero at the center of the span.

The effect of the first half-cycle of surge current is to produce a hump of electrostatic energy midway between towers in the power wire. An attempt to depict this condition is shown in Fig. 16. As a result the main wave, only a part of which is shown in Fig. 16, will be broken up in crests, superposed on the energy induced by the direct action of the storm cloud. These crests are in fact a superposed higher frequency on a single impulse. The frequency is immediately obtainable from the distance between grounding points of the grounded wire. This distance is a wave length, as shown in Fig. 15. If there are ten towers to the mile and the velocity of the traveling wave is 183,000 miles per second the frequency will be 10 × 183,000 =

1,830,000 cycles per second. With 50 grounding points per mile the frequency is 9 million cycles per second. We have all been puzzled at times to account for the high frequency effects of lightning in transmission circuits. Small inductances give remarkable choking effects at times. The foregoing theory has not yet had the test given by experimental evidence but it would seem to be one of the several possible causes of high frequency induced in a transmission line.

XIV—Self-Inductance, Natural Frequency, Maximum Current, Critical Resistance of the Grounded Wire and the Mutual Inductance with the Power Wire

On the assumption that the current in the part of the circuit which closes through the earth can be treated as an imaginary wire, an image at a depth under the surface of the earth equal to the height of the actual grounded wire above the surface of the earth, the self-inductance is 428 micro-henries for a length of overhead wire of 500 ft. (11,720 cm.) The capacitance of the grounded wire has already been found and from the combination of its inductance and capacitance its natural frequency is 640,000 cycles per second.

The maximum current of discharge is 569 amperes. The critical resistance which would just damp out oscillations is 370 ohms.

The mutual inductance between the grounded wire and the power wire is 179.8 micro-henries.

In these data it should be again noted that the distance between the earthing points of the grounded wire is 1000 ft. (23440 cm.) and is somewhat greater than is usual in practise. The effect of lesser distance between grounded points will be considered later.

These data show that with the usual resistance to ground at a tower of the order of 5 to 20 ohms, a great many oscillations will take place in this circuit before the energy will be absorbed in the resistance, since the critical damping resistance is 370 ohms. Since the mutual inductance is 42. 4 per cent of the self-inductance, a considerable percentage of this oscillation will be transferred to the power wire.

XV—Data on the Transfer of the Oscillating Surge on the Grounded Wire to the Power Wire

It is assumed now that the transmission wires are many items longer than the induced charge on the wires. Traveling waves

will therefore follow the release of the induced charge. The primary of the circuit (the grounded wire loop) contains inductance, capacitance, and resistance. The secondary, which is the power wire, contains inductance and capacitance. From this standpoint we should use the corresponding mathematical equation but it should be noted that the capacitance of the power wire is a distributed capacitance and that as soon as a part of the charge is transferred to the power wire it does not oscillate in conjunction with the grounded loop, but the induced charge is transmitted along the power wire as a traveling wave. Since this energy is lost in the mutual operation of the primary and secondary the problem is similar to a secondary circuit containing a considerable resistance which absorbs energy. If these two problems give different results, it will be necessary subsequently to choose the one which more nearly fits the actual conditions.

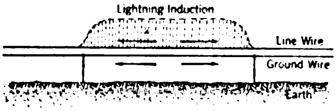


Fig. 17

Conditions of induced charges on the power wire and grounded wire at the instant of cloud discharge. Also the resulting currents.

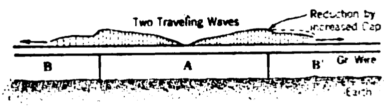


Fig. 18

The same charge as shown in Fig. 17 after it has turned into two oppositely directed traveling waves. Note the decrease in potential as each arrives at the adjacent ground loops *B* and *B'*.

Solving this problem as though the two circuits both contained concentrated inductance and capacitance without resistance it is found that the voltage induced in the secondary is 51.6 per cent of the voltage in the primary. The initial voltage in the grounded wire, acting as primary, is 105,000 volts. Therefore there would be transferred to the line on this basis a surge which has an initial voltage of 54,000 volts and a frequency somewhat over 600,000 cycles per second. The transference of energy from the local grounded wire circuit to the power wire would very quickly exhaust the supply contained in the original surge. In round numbers the wave train would run 54 kv. first peak, 27 kv. second peak, 18 kv. third peak, 9 kv. fourth peak, 4 kv. fifth peak, etc.

On the basis of using a formula for a concentrated resistance in the secondary of these coupled circuits the results will be as follows:

To get a conception of the relations of the local oscillation in

the loop of the grounded wire and the main traveling wave in a power wire, let us assume that the grounded wire is earthed only at the limits of the clouds influence.

At the instant of release, when the cloud discharges to earth, the charges on both wires start to spread simultaneously and similarly in both directions, Fig. 17. At the midway point both wires reach zero potential at approximately the same instant Fig. 18. The traveling wave on the power wire has now split into two parts and is gradually passing beyond the locality of the charged loop of the grounded wire. The grounded wire A has produced no decrease in potential of the power wire. When the surges on the power wire reach the adjacent grounded loops, B and B^1, they have their potential decreased by the added capacitance of these uncharged grounded wires.

The surge in the grounded loop continues to oscillate locally and by mutual induction, transfers a fraction of its energy to

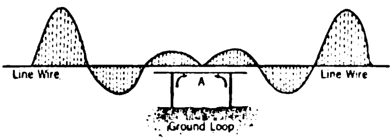


FIG. 19

Showing the tail put on to the main lightning surge by the transfer of surge energy from the grounded loop to the power wire by electromagnetic induction. The resistance of the grounded loop is less than the critical value.

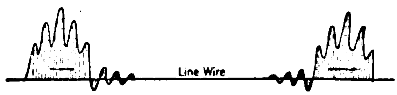


FIG. 20

Superposed higher oscillation on a traveling wave produced by the oscillations in a grounded loop.

the power wire. This transferred energy cannot add directly to the main traveling wave on the power wire because the main wave has passed beyond the influence of the grounded loop, A. The grounded loop A can do nothing more than put an attenuating tail on the main wave and make of it thereby a wave train (assuming for the present purpose that the cloud discharge has caused a simple impulse). This wave train is shown in Fig. 19.

If the induced charge of the cloud covers several grounded loops the two traveling waves should be a combination of Figs. 16 and 19, as represented in Fig. 20.

From these results we see another defect of the overhead grounded wire, namely that after it absorbs its part of the surge energy from the cloud it returns this energy to the power wire in the form of a wave train. According to the local conditions this wave train may be either superposed on the charge induced

directly by the cloud on the power wire or it may follow immediately on the heels of this traveling wave, or both simultaneously. Although the voltages of this wave train are condiserably attenuated, the wave train may do harm to insulation. Should the coils of apparatus in any part have a natural frequency corresponding to that of the wave trains, the energy of this entire wave train may be concentrated again in this local resonant point, and consequently the potential may rise to extremely high values. This resonant condition would not occur, however, if the grounded wire had not produced the wave train.

From this standpoint, therefore, it is desirable to have a resistance in the earth connections of the grounded wire which approaches the critical damping resistance. Since there are two earth connections in this circuit this resistance should be approximately 185 ohms each.

The objection to the higher resistance in the earth connection

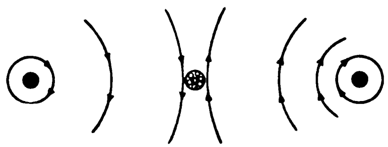


FIG. 21
A grounded wire placed on each side of a power wire so as to reduce the mutual inductance to zero.

FIG. 22
Stationary induced charge on the line before the cloud discharges.

may be found when analysis is made of the conditions of potential during a direct stroke. If, however, it is conceded that a direct stroke will invariably cause side flashes to the power wires in spite of the value of the earth resistance, this objection to the higher resistance of the gounded wire will not be valid.

In placing a parallel grounded wire, the object should be to increase the electrostatic protection and decrease the electromagnetic induction of the ground wire surge which is transferred back to the power wires. Raising the grounded wire high above the power wires decreases the electromagnetic induction but unfortunately decreases also the electrostatic protection.

A better method of reducing the electromagnetic induction is to employ two grounded wires and place them symmetrically on each side of a power wire or group of power wires. Such a condition of zero electromagnetic induction is shown in Fig. 21.

As a third means of reducing the transfer of surge energy from

the grounded wire to the power wire, the use of critical damping resistance in the grounded loop has already been mentioned.

XVI—Movements of Induced Charges on Line Wires Coincident with the Movements of Charges in a Cloud

So far the assumption has been made that the electrostatic charge on a line starts from a stationary condition at the instant a lightning bolt takes place between the cloud and earth. A stationary charge first collects gradually under the storm cloud. This induced charge is distributed along the line over a distance somewhat greater than the length of cloud, Fig. 22. Coincident with the discharge to earth there is also a collection of the accumulated charge on the line towards one point. This point has been called the bolt peak and is the point on the line nearest to the point on the earth struck by the cloud discharge. In the usual thunder cloud the quantity of electricity in the vertical discharge from the cloud has been gathered from some distance horizontally in the cloud and therefore there will be a corresponding movement of the electrostatic charge on the line as represented in Fig. 23. This preliminary shifting of the charges on the power wires and grounded wires will cause some loss of energy by induction in the grounded loop. If the charge traveling on the line wires can be retarded by means of choke coils, especially those which absorb high frequency energy, it may be possible to materially decrease the peak of potential on the line wire. This is still an indeterminate condition which should be decided by experimental data on the rapidity of movement and the quantity of electricity which would be concentrated by this particular effect of the lightning discharge. On the side of the retardation by inductance it is evident that only a limited amount of concentrated reactance is permissible on the line.

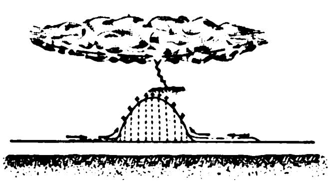


Fig. 23

Concentration of charge on the line at the instant of cloud discharge and coincident with the corresponding movements of charge in the cloud.

If these reactances in the power wires are staggered they will become a help in reducing the potentials of lightning by breaking up the waves. Such a possible effect is shown in Fig. 24 for two parallel wires in which the charge on one is retarded behind the charge on the other and therefore the capacitance of the

adjacent wire becomes available in absorbing the charges electrostatically, thereby reducing the potential. Reflections take place at each coil, which again give time for the absorption of the surge energy on the line by the parallel grounded wire. The more the charges can be absorbed on the line the less the amount to reach the apparatus in the stations.

The best type of high-frequency absorbing reactance is the one with distributed resistance between turns. A partially conducting cement is used which serves both as a mechanical support and as an electrical resistance, Fig. 25. As the surge potential piles up on each turn of the coil it forces current through the distributed resistance between turns. Thereby the recoil from stored magnetism is avoided and a part of the surge energy is transformed into heat energy. The steeper the wave front

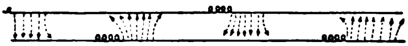


FIG. 24

Illustration of a method of breaking up a traveling wave by retardation, reflection, and absorption by specially designed choke coils placed in staggered position in the three-phase wires. A traveling wave meets the absorber choke coil and three things take place, namely, it is partially absorbed by the shunting resistance from turn to turn, it is partially reflected by the inductance, and it is partially transferred to the adjacent wire by dielectric displacement (as indicated by the arrows). This displaced charge is divided into two parts and one part travels in the opposite direction to the original wave. Thereby a traveling wave is broken up into many parts and dissipated.

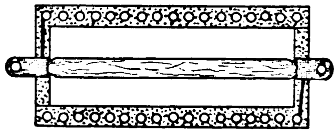


FIG. 25—ABSORBED TYPE OF CHOKE COIL

A choke coil made of bare wires cast in a semi-conducting cement. This gives a distributed leakage which is more effective than shunting the entire coil with a simple resistance. Every turn as it chokes back the surge and raises the potential of it, causes an absorption of its energy by forcing the current through the shunting resistance.

and the higher the frequency the more efficient is the ábsorption of surge energy. In other words, the more severe the surge, the more it is forced through the resistance.

XVII—THE ABSORPTION OF THE TRAVELING WAVES BY THE SUCCESSIVE LOOPS OF THE GROUNDED WIRE

We have just discussed an objectionable feature of the grounded wire in producing a wave train on the power wire and we now come to a condition which is more favorable to the grounded wire. Lightning impulses and all the succeeding traveling waves trains which pass along the power wire must have their electromagnetism looped into every successive grounded wire loop. Thereby each of these grounded loops will have transferred to it a fraction of the energy of the traveling wave and this energy will be more or less absorbed according to the value of the ohmic

resistance in the grounded loop. Again, we come to the desirability of having a comparatively high resistance in the grounded loop. This resistance should either be in the earth connection or inserted in series in a wire circuit. In this way the grounded wire will serve as an absorber of traveling waves and should give efficient absorption in all cases except where the induced lightning is near a station and has only a short distance to travel.

If there is no appreciable absorption of energy in the grounded loop, the effect of the grounded loop will be to break up the main traveling impulse into a long wave train of a wave length corresponding to the length of the grounded loop. Thereby a single impulse from a cloud will be transformed into a long train of waves at very high frequency.

XVIII—The Frequency of the Lightning Bolt

So far the assumption is made that the cloud discharge does not oscillate between the cloud and earth. Prof. Elihu Thomson has shown that some parts of the path of discharge in the cloud itself have too much resistance in their paths to permit of a free oscillation. Mr. De Blois' records on an oscillograph (A. I. E. E. Transactions, Vol. XXXIII, 1914, p. 519) have shown this effect. There is, however, low resistance in the main path of the lightning discharge and therefore a possibility of local oscillations between the ends of this conducting streak. Since the length of the conducting streak is comparatively short, its frequency, if it exists, is relatively high, perhaps of the order of 200,000 cycles to a million cycles per second.

Any such oscillation will induce a corresponding oscillation on the transmission line, and will be added to the natural oscillations already discussed. It should be noted that any oscillation induced by an oscillation of a cloud discharge will add surge energy to the power wires at each alternation. The original quantity induced on the line cannot return to the starting point when once freed by the initial action of the cloud discharge. The initial charge takes the form of two traveling waves and there is not much more argument in favor of their return with the oscillation of the cloud discharge than there is that a rifle bullet will return to a gun by the force of the air which rushes into the muzzle after the bullet passes out. The traveling wave, like the rifle bullet, possesses dynamic energy which keeps it traveilng once it is set in motion along the line wires.

So each succeeding oscillation of a cloud discharge will start

a new oscillation on the line and will thereby produce a wave train which has a greater energy than the original induced charge.

XIX—The Effect of the Combination of Lightning Voltage and Power Voltage at the Instant the Bound Charge is Set Free on the Line

At the instant the cloud discharges to earth these two sets of voltages both appear on the line. The power voltage at one instant has one phase positive, another phase negative, and the third phase at zero potential. If the lightning potential is positive the corresponding quantities of electricity will combine or cancel, leaving an inequality in the voltage of the traveling waves which depart from this point. This subject has been discussed in a previous article by the writer and is of especial interest in the subject of the arcing ground suppressor. It is another factor which adds complication to any exact calculations of what actually takes place during and subsequent to a lightning discharge. This phenomenon may produce a material decrease in the surge potential by causing waves to travel in the three phases one ahead of the other, the stronger holding the weaker one back by electromagnetic induction. As a result it is possible that equally induced charges on the three phases, which have equal tendencies initially to oscillate towards earth may be thrown out of relative location on the longitudinal length of the circuit and thereby produce line to line surges.

XX—High Frequency Produced in Apparatus by Transposition of Power Wires

Transpositions of power wires are made with two purposes, at least, in view, namely, first to decrease the induction on parallel lines, and second to prevent shifting of the neutral of the circuit. Our present interest is centered in the second purpose.

If the power wires are hung in a vertical plane the lowest wire will have the greatest capacitance to earth, and the highest wire the least. If there are no transpositions of the phase wires there is a tendency to shift the neutral from the center of the three phase triangle. If the neutral of the circuit is grounded, this shifting tendency will produce a current at the neutral connection to earth. The current passing to earth will be such as to satisfy the unbalanced capacitances of the phase wires.

If the neutral is not grounded the tendency to shift will cause an actual shifting of the neutral throughout the system. The shifted point will be permanent.

A single phase simplifies the illustration, Fig. 26. To get the direction of shift of the neutral, without mathematical analysis make the capacitance of the lower wire many times greater than the upper wire. Practically this can be done by closing the disconnecting switch on the lower wire and leaving the other disconnecting switch open. As a result the transformer gives the effect of being grounded by the lower wire. The capacitance of the lower wire is so great as compared to the capacitance of the coils of the transformer that the potential of the connected side is reduced sensibly to zero.

Now, if the upper line wire is connected to the transformer, the two sides will be more nearly balanced but the lower wire

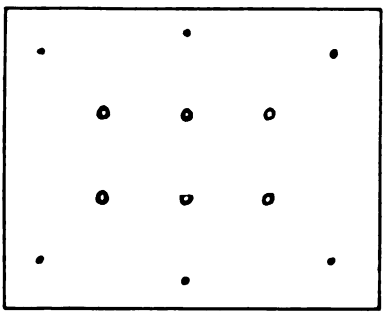


FIG. 26

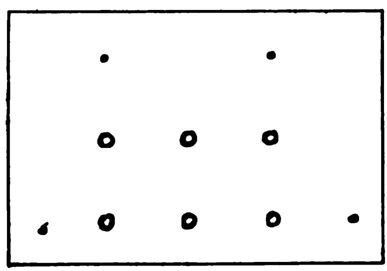


FIG. 27

will still have the greater capacitance and therefore the neutral will remain shifted from the midpoint of the transformer coils as indicated in Fig. 26.

Incidentally it might be noted in passing that the arcing at the switch contact in opening on one line wire alone causes rapid shifting of potential in the transformer at every break of the arc. If the length of line is such as to resonate with the natural frequency of the transformer coils, and especially if the transformer coils are not designed to break up the surges into several different frequencies, it is possible to get local resonance in the transformer coils. Such resonance will produce high voltages.

Our problem is the production of high frequencies, especially at the time of switching, not by arcing, but by the transposition of the phases along the line. Fig. 27 shows a transformer being

closed on a transposed line. In the first section wire x is the lower one and the neutral of the transformer will be shifted from the midpoint M to a point 1. As the traveling wave runs along the second section the circuit becomes unbalanced on the opposite side and the neutral shifts across the midpoint to a point 2. There is a sudden shift for every section the traveling wave passes which throws a high frequency into the transformer windings. The frequency (neglecting higher harmonics) can be found by dividing the velocity of light by twice the number of miles per transposition. For example, if the line is transposed every five miles, the frequency produced by closing a switch on to this dead line will be 18,300 cycles per second.

$$\left[(183{,}000 \text{ miles per second}) \div 2 \times 5 = 18{,}300 \right]$$

At 60 cycles or any frequency low as compared to the natural frequency of the line the successive sections of transposition cancel the unbalanced currents and as a result there will be no shifting of the neutral. There can be no such cancellation for a traveling wave because the charging currents do not flow to the several sections simultaneously, but successively.

The degree of unbalancing depends upon the relation of the capacitance of the coils of the transformer to the difference in capacitances of the line wires. As an example, the following data are used: Two line wires No. 000 (one cm. diameter) are vertically hung and transposed every five miles. The upper wire is 66 ft. high (2000 cm.) and the lower wire 40 ft. high (1210 cm.) The capacitance of the upper wire to earth is 10.2 milli-mf. per mile (0.0557 statfarad per cm.) and of the lower wire 10.55 milli-mf. per mile (0.0590 statfarad per cm.)

If the quantities emanating from each wire are assumed to be equal, the potential of the upper wire will be 7 per cent greater than the lower wire. If, on the other hand, the potentials are assumed to be equal the quantity on the lower wire will be 5 per cent greater than the quantity on the upper wire. If the neutral of the circuit is not grounded both the charges and the potentials will change somewhat. The voltage of the upper wire will differ by less than 7 per cent from the lower wire. Since this difference is so small it is hardly worth while to make careful calculations. We may assume approximately that the shifting of neutral is about 4 per cent of the potential of one wire. It is evident that such a slight variation in potential even at high frequencies can do no harm to transformer coils except

perhaps in the rare case of resonance between the coils and this high frequency.

General Survey of Protection by Overhead Grounded Wire

It is impossible to make definite recommendations which will cover all conditions of transmission circuits. There is much territory where lightning is not prevalent and therefore the expense of the overhead wire may well be avoided. There are also cases where spurs of circuits are carried out to small consumers where the financial returns do not warrant the expense. If such a circuit, when damaged, can be made to free itself from the main circuit without a general interruption, the use of a grounded wire can be questioned. There may be still another case where, theoretically at least, the overhead wire may not be necessary. This condition will occur when the insulation of the transmission line is so high that an induced stroke cannot flash over the insulators. In other words, the insulators cannot be flashed over except by a direct stroke. With the suspension type insulators and the tower carr'ed well above the insulators the parallel grounded wire would then be of no particular value. What the dielectric strength of such an insulator must be is not known.

In the majority of transmission circuits, however, the problem is rather of the nature of how many overhead grounded wires to use and where to place them to get the greatest advantage. Certain mechanical conditions will limit the freedom of choice of location. For example, with the usual suspension type of construction it may be unwise to install overhead grounded wires in the same horizontal plane as the power wires, due to the chances of grounding by side swinging. At any rate, the wider tower would be materially more expensive. Under such conditions the overhead wires would naturally be strung either above or below.

In the case, however, of pin type construction the grounded wires may be placed laterally as well as above the power wires.

Various locations of grounded wires are shown in Figs. 26, 27, 28, 29, and 30.

Fig. 26 shows two parallel circuits of six wires arranged in horizontal formation and six grounded wires separated as widely as possible from each other and yet as near to the power wires as mechanical clearance will permit. The grounded wires are ar-

ranged in pairs symmetrically so as to decrease the electromagnetic induction. The two outside lower wires might be raised to the same position as the corresponding one in Fig. 27 without making much difference in the protective value, or the two upper outside wires might be lowered on each side without making a very great difference in the protection. Mechanical conditions of support will be the criterion. The simple rule is to space the overhead grounded wires as far from each other as convenient, but as near to the power wires as is safe.

Fig. 27 shows a desirable location for four grounded wires on the same type of circuit as Fig. 26.

Fig. 28 shows a distribution of six grounded wires for two three-phase circuits vertically hung. In some cases it may be desirable

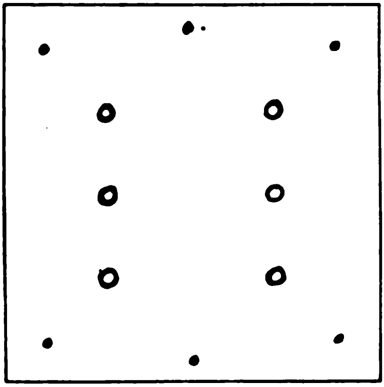


FIG. 28

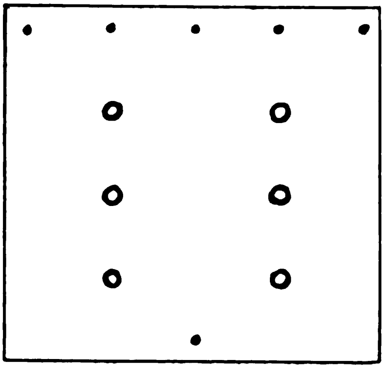


FIG. 29

to keep the grounded wires within the same width as the two circuits.

Fig. 29 shows another disposition of the six grounded wires which is not so good from the electromagnetic standpoint but which is somewhat better from an electrostatic standpoint. It has already been shown that the lower wires of the vertically hung circuits are greatly protected by their lesser height above earth and therefore they do not need the presence of grounded wires as much as the upper power wires.

Fig. 30 shows a desirable distribution of four grounded wires where non-grounded pins on the insulators are used. To preserve the insulation afforded by the wooden cross-arm the metallic connections of the laterally grounded wires are carried free of the cross-arm, in fact, long metal braces might be used in this case. At one point in the circuit is shown a series resistance to

bring the total resistance in the grounded loop up to a value at least equal to one-fifth of the critical damping resistance.

From an electrical standpoint grounded wires of small diameter can be used. From a mechanical standpoint the size of the wire is dictated by the length of span. From calculation of loading of the wire under sleety conditions the practise calls for about a 3/8-in. (9.5 mm.) stranded Siemens-Martin steel wire for a span of 600 ft. (182 m.), ¼-in. (6.3 mm.) for a span of about 250 ft. (76 m.), and the ordinary telegraph wire for spans of about 100 ft. (30. m.).

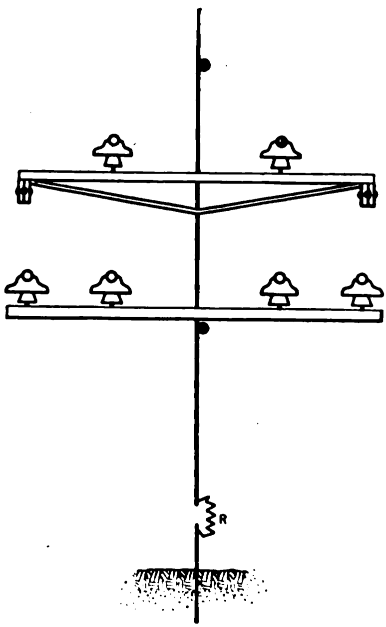


Fig. 30

The cost of the ⅜-in. (9.5 mm.) steel wire will vary according to the cost of the metal and the cost of stringing, being usually somewhat greater than \$100 per mile rather than less although \$100 per mile is a convenient figure to use for comparisons. The total cost of electrical circuits, including the towers, varies from \$2000 to \$12,000 per mile. Each over-head grounded wire adds to the cost from 5 per cent to 1 per cent of the cost of a line. Since the use of several grounded wires gives such a large percentage of protection against lightning strokes in most cases they are justified. If line protection could be made so thorough as to do away with large installations of steam auxiliaries in local substations the cost of parallel grounded wires would drop immediately to a relatively insignificant figure.

MATHEMATICAL EQUATIONS

Following are the general equations for a single overhead wire and a parallel cylindrical storm cloud:

$$V_1 = \left(4.6 \log_{10} \frac{m_{11}}{r_1}\right) q_1 + \left(4.6 \log_{10} \frac{m_{c1}}{r_{c1}}\right) q_c \qquad (1)$$

$$V_c = \left(4.6 \log_{10} \frac{m_{1c}}{r_{1c}}\right) q_1 + \left(4.6 \log_{10} \frac{m_{cc}}{r_c}\right) q_c \qquad (2)$$

Where $V_1 =$ potential of the wire

$V_c =$ potential of the cloud at its surface

$q_1 =$ statcoulombs per cm. of length of wire

$q_c =$ statcoulombs per cm. of cloud

$m_{11} =$ distance in cm. from the image of wire 1 to the surface of wire 1 = 2000 cm.

$r_1 =$ radius of wire 1 = .5 cm.

$m_{c1} = m_{1c} =$ distance from the image of the cloud to wire 1 = 56,000 cm.

$r_{c1} = r_{1c} =$ distance from the apex of charge in the cloud to wire 1 = 54,000 cm.

$m_{cc} =$ distance from the image of the cloud to the surface of the cloud = 100,000 cm.

$r_c =$ distance from the apex of the cloud charge to the lower surface of the cloud = 10,000 cm.

On substituting these values, equations **3** and **4** are obtained:

$$V_1 = 16.6\, q_1 + .0727\, q_c = 0, \qquad q_c = 5700 \tag{3}$$

$$V_2 = .0727\, q_1 + 4.6\, q_c = V_2 \qquad V_2 = 26{,}200 \tag{4}$$

For two parallel wires in a horizontal plane, both grounded, the quantities are found from the following relations where 414.7 is the potential of the undisturbed field at 1000 cm. above the earth.

$$V_1 = 0 = 16.6\, q_1 + 6.0\, q_2 - 414.7 \tag{5}$$

$$V_2 = 0 = 6.0\, q_1 + 16.6\, q_2 - 414.7 \tag{6}$$

$$q_1 = q_2 = 18.36 \text{ statcoulombs per centimeter} \tag{7}$$

$$\text{Electrostatic energy} = \frac{1}{2} q_1 V_1 = \frac{1}{2} \times 18.36 \times 414.7$$

$$= 3805 \text{ statjoules per cm.} \tag{8}$$

For comparison of one of two wires to one wire alone:

$$\text{(One wire only) Energy} = \frac{1}{2} \times 25 \times 414.7$$

$$= 5180 \text{ statjoules per cm.} \tag{9}$$

Capacitance of one of two wires to ground = .0443 statfarad per cm. (**10**)

Capacitance of one wire to ground = .0603 statfarad per cm (**11**)

The general relations of potential in statvolts and quantity in statcoulombs per cm. length of wire are given below:

$$V_1 = \left(4.6 \log_{10} \frac{m_{11}}{r_1}\right) q_1 + \left(4.6 \log_{10} \frac{m_{21}}{r_{21}}\right) q_2 - (\text{gradient} \times \text{height (1)}) \quad \mathbf{(12)}$$

$$V_2 = \left(4.6 \log_{10} \frac{m_{12}}{r_{12}}\right) q_1 + \left(4.6 \log_{10} \frac{m_{22}}{r_2}\right) q_2 - (\text{gradient} \times \text{height (2)}) \quad \mathbf{(13)}$$

Notation is similar to that of equations **1** and **2**. The second wire is No. 2 and the effect of the cloud is simplified to the expression, " gradient × height of wire."

The equations for induced quantity on 5 wires (4 grouped around one, height of 1000 cm., spacing 100 cm., see Fig. in text) are as follows:

$$V_1 = 0 = 16.6\, q_1 + 12.0\, q_2 + 6.1\, q_3 + 5.9\, q_5 - 414.7 \quad \mathbf{(14)}$$

$$V_2 = 0 = 6.0\, q_1 + 21.2\, q_2 + 5.4\, q_3 + 5.2\, q_5 - 414.7 \quad \mathbf{(15)}$$

$$V_3 = 0 = 6.1\, q_1 + 10.8\, q_2 + 16.76\, q_3 + 4.6\, q_5 - 455.8 \quad \mathbf{(16)}$$

$$V_5 = 0 = 5.9\, q_1 + 10.4\, q_2 + 4.6\, q_3 + 16.36\, q_5 - 373.0 \quad \mathbf{(17)}$$

$q_1 = 8.45$, $q_2 = q_4 = 11.45$, $q_3 = 14.4$, and $q_5 = 8.4$.

To get the protection and potential ratio due to the use of a parallel grounded wire:

Symbolical solution for potential ratios of two wires in a horizontal plane, one of which is a parallel grounded wire. The initial induction is given by equations **12** and **13**, or simplified:

$$V_1 = 0 = a\, q_1 + b\, q_2 - (\text{gradient} \times \text{height of wires}) \quad \mathbf{(18)}$$

$$V_2 = 0 = b\, q_1 + d\, q_2 - (\text{gradient} \times \text{height of wires}) \quad \mathbf{(19)}$$

Let k be the undisturbed potential at the height of the wires

Then

$$q_1 = \frac{d - b}{ad - b^2}\, k, \qquad q_2 = \frac{a - b}{ad - b^2}\, k \quad \mathbf{(20)}$$

After the cloud discharges the charge on wire 1, the grounded wire, will pass to earth and wire 1 will take an induced charge q^1.

$$V_1 = 0 = -a\,q' + b\,q_2 \quad \text{whence } q' = \frac{b}{a}\,q_2 \tag{21}$$

Substituting this in the new equation for the potential of wire 2

$$V_2 = -b\,q' + d\,q_2 = \left(d - \frac{b^2}{a}\right) q_2 \tag{22}$$

Substituting the value of quantity on wire 2 from equation **20** gives for the potential of the power wire:

$$V_2 = \frac{ad - b^2}{a} \quad \frac{a - b}{ad - b^2}\,k = \frac{a - b}{a}\,k \tag{23}$$

The potential of wire 2 without protection of wire 1 is

$$V_2' = k, \text{ therefore} \tag{24}$$

$$\frac{V_2 \text{ protected}}{V_2' \text{ unprotected}} = \frac{a - b}{a} \tag{25}$$

In which these coefficients are the same as given in equations **12** and **13**

$$a = 4.6 \log_{10} \frac{m_{11}}{r_1} \text{ and } b = 4.6 \log_{10} \frac{m_{12}}{r_{12}} \qquad \text{(26) and (27)}$$

$$d = 4.6 \log_{10} \frac{m_{22}}{r_2} \tag{28}$$

The protection is independent of the coefficient (d) which depends on the size of the power wire. If the grounded wire is above the power wire the ratio would be increased in direct proportion to the percentage height, then

$$\frac{V_2 \text{ protected}}{V_2' \text{ unprotected}} = \frac{a - b}{a} \times \frac{\text{height of gr. wire}}{\text{height of power wire}}$$

If, on the other hand, the grounded wire is below, the fraction containing the heights is inverted.

Protection afforded by two grounded wires with a power wire symmetrically placed between them, all three wires in a horizontal plane. The outside wires, No. 2 and 3, will have equal quantities of electricity induced on them. The general equations are:

$$V_1 = a\,q_1 + b\,q_2 + b\,q_3 + k \tag{29}$$

$$V_2 = b\,q_1 + c\,q_2 + d\,q_3 + k \tag{30}$$

With the wires at zero potential and the cloud charge negative,

$$V_1 = 0 = a\,q_1 + 2\,b\,q_2 - k \tag{31}$$

$$V_2 = 0 = b\,q_1 + (c + d)\,q_2 - k \tag{32}$$

$$q_1 = \frac{c + d - 2b}{a\,(c + d) - 2b^2}\,k \tag{33}$$

Immediately after the lightning discharges

$$V_2 = 0 = b\,q_1 - (c + d)\,q',\quad q' = \frac{b}{c + d}\,q_1 \tag{34}$$

$$V_1 = a\,q_1 + 2\,b\,q' = \frac{a\,(c + d) + 2b^2}{c + d}\,q_1$$

$$= \left(1 - \frac{2\,b}{c + d}\right)k \tag{35}$$

As before (k) disappears in the potential ratio which becomes

$$\left(1 - \frac{2b}{c + d}\right)$$

$$\text{The protection} = \frac{2\,b}{c + d} \tag{36}$$

If instead ,of taking the two grounded wires equally spaced from the power wire, they should have been unequal, spaced,

then $2b$ becomes two separate factors, say $(b + f)$, and the protection from two parallel grounded wires becomes

$$\text{protection} = \frac{b + f}{c + d} \tag{37}$$

$$\text{Where } b = 4.6 \log_{10} \frac{m_{21}}{r_{21}}, \quad \left\{ \begin{array}{l} m_{21} = \text{image 2 to wire 1} \\ r_{21} = \text{spacing wires 2 and 1} \end{array} \right\} \tag{38}$$

$$f = 4.6 \log_{10} \frac{m_{31}}{r_{31}}, \quad \left\{ \begin{array}{l} m_{31} = \text{image 3 to wire 1} \\ r_{31} = \text{spacing wires 3 and 1} \end{array} \right\} \tag{39}$$

$$c = 4.6 \log_{10} \frac{m_{22}}{r_2}, \quad \left\{ \begin{array}{l} m_{22} = \text{image 2 to wire 2} \\ r_2 = \text{radius} \end{array} \right\} \tag{40}$$

$$d = 4.6 \log_{10} \frac{m_{32}}{r_{32}}, \quad \left\{ \begin{array}{l} m_{32} = \text{image 3 to wire 2} \\ r_{32} = \text{spacing wires 3 and 2} \end{array} \right\} \tag{41}$$

Since the grounded wires are assumed to be the same diameter and the same height $\frac{m_{22}}{r_2} = \frac{m_{33}}{r_3}$

To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

(*Subject to final revision for the Transactions.*)

APPLICATION OF A POLAR FORM OF COMPLEX QUANTITIES TO THE CALCULATION OF ALTERNATING-CURRENT PHENOMENA

BY N. S. DIAMANT

ABSTRACT OF PAPER

In the *calculation* of alternating current phenomena by means of complex quantities, as a rule, the rectangular components of the vector are used, and the rectangular form involving the operator $j = \sqrt{-1}$ is more common than the polar or exponential forms which involve the operators $(\cos\theta + j\sin\theta)$ or $\epsilon^{j\theta}$; although it is recognized that the latter are very convenient in certain cases.

A simple method for dealing directly with the vectors themselves is described in the paper and it consists in introducing the operator j^n, where n, contrary to ordinary usage, may be any positive or negative fraction. Just as j or j^1 rotates the quantity before which it is placed through 1×90 degrees, so j^n rotates the number into which it is multiplied through $n \times 90$ degrees.

The operator j^n follows the rules of ordinary algebra and according to these the different algebraic operations of multiplication etc., are developed in section II. In section III a few illustrative problems are given; these are followed by a critical resume in section IV. At the end, for convenience of reference a summary of formulas is given, and a very short bibliography is included.

I—INTRODUCTION

ACCORDING to the usual method of dealing analytically with alternating current problems a stationary vector[1] representing the harmonic quantity under consideration, is expressed algebraically by a complex number of the following forms:

(*a*) The rectangular form, (see Fig. 1).

$$\dot{E} = e + je' \qquad (1)$$

1. As to the classification of vectors into stationary, rotative, non rotative, etc. an interesting paper by A. E. Kennelly, TRANS. A. I. E. E. June 1910, may be consulted. It should be noted, in this connection, that in electrical engineering we deal with two-dimensional *vector representation of harmonic quantities* rather than the two- or three-dimensional, non-localized true vectors of vector analysis or quaternions.

Manuscript of this paper was received April 8, 1916.

where e and e' are the rectangular coordinates of the point representing the complex number.

(*b*) The polar form, (see Fig. 1).

$$\underset{\cdot}{E} = E\ (\cos\theta + j\sin\theta) \tag{2}$$

where $E = \sqrt{e^2 + e'^2}$, and $\theta = \tan^{-1}\left(\frac{e'}{e}\right)$, are the polar co-ordinates of the same point representing the same complex number. Equation (2) can also be written in the exponential form by means of the identity,

$$(\cos\theta + j\sin\theta) \equiv e^{j\theta}$$

Thus

$$\underset{\cdot}{E} = E e^{j\theta} \tag{3}$$

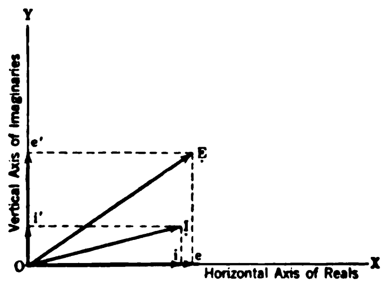


Fig. 1

Convenient and useful as it is in engineering problems (whether electrical, civil or mechanical) involving vectors, to resolve these into two rectangular components, it is preferable at times to deal directly with the vectors themselves. Indeed, it is not uncommon in the derivation of general expressions for regulation, etc., to use vectors rather than their components; for instance, the (primary) impressed voltage of a transformer may be written as

$$\underset{\cdot}{E}_1 = \underset{\cdot}{E}_{i1}(1 + \underset{\cdot}{Z}_1\,\underset{\cdot}{Y}_0 + \underset{\cdot}{Z}_1\,\underset{\cdot}{Y}/a^2),\ \text{instead of,} \tag{4}$$

$$= e_{i1}\left[1 + r_1\left(g_0 + \frac{g}{a^2}\right) + x_1\left(b_0 + \frac{b}{a^2}\right) + jx_1\left(g_0 + \frac{g}{a^2}\right) - jr_1\left(b_0 + \frac{b}{a^2}\right)\right] \tag{5}$$

Equation (4) not only looks simpler than (5) but it is a much better ***mathematical shorthand***, so to speak, since it allows at a glance to see into the physical meaning of the expression; this is very important and valuable in engineering, both from a practical and educational point of view. Translating (4) into words it will be seen that it states in a simple and direct manner that the voltage impressed upon a transformer = (the primary induced voltage) + (the exciting current, $E_{i1} Y_0$, times the primary impedance Z_1) + (the load current [reduced to primary] times the same impedance Z_1); where the plus sign signifies vector addition.

In *actual calculations*, however, so far as the writer is aware, in standard a-c. engineering works or technical papers use is made of expression (5) rather than such an equation as

$$\underset{\bullet}{E}_1 = e_{i1}\left[1 + Z_1 e^{j\alpha}\left(Y_0 e^{-j\beta} + \frac{Y}{a^2}\ e^{-j\gamma}\right)\right]$$

$$= e_{i1}\left[1 + Z_0\ Y_0\ e^{j(\alpha-\beta)} + Z_1\frac{Y}{a^2}\ e^{j(\alpha-\gamma)}\right] \qquad (6)$$

The object of the paper is to discuss briefly the use of a simple polar form of complex quantities and indicate some of its advantages when used either by itself or in combination with the usual methods.

II—Principles

1. *General.* A sinusoidal e. m. f. or current may be represented by (see Fig. 1)

$$\underset{\bullet}{E} = e + je'$$

$$\underset{\bullet}{I} = i + ji'$$

where the symbol $j\ (= \sqrt{-1})$, as it is well known, rotates the quantity before which it is placed through 90 deg. However, since j follows the laws of *ordinary algebra* it is entirely plausible, and interesting to enquire into the meaning of j^n, where n, contrary to common usage is not an integer but any positive or negative number.

Just as j or j^1 indicates rotation through 90×1 deg. and j^3 indicates rotation through 90×3 deg., so $j^{\frac{1}{2}}$ must be interpreted as rotation through $90 \times \frac{1}{2} = 45$ deg. In general $Aj^{\alpha}\ (\alpha > 0)$

may be interpreted as rotation of the number A through $90 \times \alpha$ deg. or $\frac{\pi}{2}\ \alpha$ radians in the positive or counterclockwise direction; similarly: $Aj^{-\alpha}$ $(\alpha > 0)$ represents a vector which has been turned through $\alpha \frac{\pi}{2}$ radians in the negative direction. Thus the exponent of j may be any number and it indicates the phase relation of the quantity under consideration. For instance, an e. m. f. of E volts and 60 deg. out of phase with the current will be represented according to the above, as $\underset{\cdot}{E} = E\, j^{2/3}$ where $\alpha = (60/90) = 2/3$ and $\underset{\cdot}{I} = I\, j^{\circ} = I$, since j to the zero power $= 1$, just as for any other algebraic quantity.

If desired the above statements can also be proven by means of De Moivre's theorem, as follows:

$$(\cos\theta + j\sin\theta) = \left(\cos\alpha\frac{\pi}{2} + j\sin\alpha\frac{\pi}{2}\right) \equiv \left(\cos\frac{\pi}{2} + j\sin\frac{\pi}{2}\right)^{\alpha}$$
$$\equiv j^{\alpha}$$

i. e., the operator j^{α} is identical with $(\cos\theta + j\sin\theta)$, where $\theta = \frac{\pi}{2}\,\alpha.$

2. *Multiplication and Division.* As we have seen a vector $\underset{\cdot}{A}$ can be represented as:

$$\underset{\cdot}{A} = a + ja', \text{ or} \tag{7'}$$

$$\underset{\cdot}{A} = A\, j^{\alpha} \tag{7}$$

Similarly a vector $\underset{\cdot}{B}$ can be written as:

$$\underset{\cdot}{B} = b + jb', \text{ or} \tag{8'}$$

$$\underset{\cdot}{B} = B\, j^{\beta} \tag{8}$$

According to the ordinary method,

$$\underset{\cdot}{A}\underset{\cdot}{B} = (ab - a'\, b') + j\,(ab' + a'\, b) \tag{9}$$

But $a = A\cos\alpha^{\circ}, a' = A\sin\alpha^{\circ}; b = B\cos\beta^{\circ}$ and $b' = B\sin\beta^{\circ}$ where $\alpha^{\circ} = (90\,\alpha)$ deg., and $\beta^{\circ} = (\beta\, 90)$ deg.

Substituting in equation (9) we get:

$$AB = AB(\cos(\alpha^{\circ} - \beta^{\circ}) + j\sin(\alpha^{\circ} - \beta^{\circ}))$$

The last expression according to the notation under discussion becomes:

$$\underset{\cdot}{A}\underset{\cdot}{B} = AB\, j^{(\alpha+\beta)} = Cj^{\delta}\,. \tag{11}$$

Translating (**11**) into words it will be seen that the product of two harmonic quantities represented, as vectors A and B by means of complex quantities of the form (**7**) or (**7′**) and (**8**) or (**8′**) is equal to a new quantity $C = AB$ turned through $\left(\frac{\pi}{2}\,\delta\right)$ radians with respect to the reference axis.

Similarly it will be seen that,

$$\frac{\underset{\cdot}{A}}{\underset{\cdot}{B}} = \frac{A}{B}\, j^{(\alpha-\beta)} \tag{12}$$

If in equation (**12**) $\underset{\cdot}{A}$ represents an e. m. f. and $\underset{\cdot}{B}$ a current produced by it, their quotient, the impedance of the circuit, is given by:

$$\underset{\cdot}{Z} = Zj^{\gamma}$$

where $Z = A/B$ and $\gamma = (\alpha - \beta)$. In this connection it is of interest to consider in a little detail the meaning of the reciprocal of a plane vector, such as $\underset{\cdot}{Z} = Z\,j^{\gamma}$

Let $\underset{\cdot}{Y}$ be the reciprocal of $\underset{\cdot}{Z}$; then by definition,

$$\begin{aligned} \underset{\cdot}{Y}\underset{\cdot}{Z} &= 1 = (\,Yj^{\epsilon}\,)\ (Zj^{\gamma}\,) \\ &= YZj^{(\epsilon+\gamma)} = 1\,j^{0} \end{aligned}$$

$$i.e., (\epsilon+\gamma) = 0 \text{ or } \epsilon = -\ \gamma.$$

In short, it is seen that the reciprocal of a vector $\underset{\cdot}{Z} = Zj^{\gamma}$ is a new vector turned through $(-\ \gamma)\ \frac{\pi}{2}$ radians and having a length equal to $(1/Z)$. The great simplicity of this result is not, of course, unknown in connection with the exponential representation of a vector; but it is not shared with the ordinary notation, and the average student or even engineer is loath to use such expressions as:

$$\underset{\cdot}{Y} = \left(\frac{r}{Z^2} - j\,\frac{X}{Z^2}\right) = (g - jb)$$

since the admittance $\underset{\cdot}{Y}$ in terms of r, x and Z is rather involved and *its physical meaning* is not quite apparent.

In general the product or quotient of any number of vectors can readily be written down:

$$\frac{\underset{\cdot}{A}\underset{\cdot}{B} \text{ etc.}}{\underset{\cdot}{C}\underset{\cdot}{D} \text{ etc.}} = \frac{AB \text{ etc.}}{CD \text{ etc.}}\, j^{(\alpha+\beta \text{ etc.}) - (\gamma+\delta \text{ etc.})} \tag{13}$$

3. *Addition and Subtraction.* Consider two vectors, $\underset{\cdot}{A}$ and $\underset{\cdot}{B}$:

$$\underset{\cdot}{A} = A j^{\alpha} = a + ja' \tag{14}$$

$$\underset{\cdot}{B} = B j^{\beta} = b + jb' \tag{15}$$

Their sum $\underset{\cdot}{C}$ in terms of rectangular components is:

$$\underset{\cdot}{C} = C j^{\delta} = (a + b) + j\,(a' + b') \tag{16}$$

whence, placing $\alpha' = \frac{\pi}{2}\,\alpha$ and $\beta' = \frac{\pi}{2}\,\beta$,

$$C^2 = A^2 + B^2 + 2\,AB \cos\,(\beta' - \alpha') \tag{17}$$

This follows also directly from elementary trigonometry, (see Fig. 2).

The phase angle $\delta' = \frac{\pi}{2}\,\delta$ can be calculated by means of one of the following expressions.

$$\delta' = \tan^{-1} \frac{A \sin \alpha' + B \sin \beta'}{A \cos \alpha' + B \cos \beta'} \tag{18}$$

$$= \alpha' + 2\left(\sin^{-1} \sqrt{\frac{S\,(S - B)}{AC}}\right) \tag{19}$$

where $\quad 2\,S = A + B + C.$

Similarly the sum of three or more vectors can be obtained by the use of the above formulae; however, judgment should be exercised in the choice of the method or methods to be used in any given problem in order to simplify calculations as much as possible. Thus in case of more than two vectors it may be more convenient to obtain the resultant by means of the rectangular form of complex quantities.

To find the difference of any two vectors $\underset{\cdot}{A}$ and $\underset{\cdot}{C}$ (see Fig. 3) it may be noted that if $\underset{\cdot}{A} = A\,j^{\delta}$ then $-\underset{\cdot}{A}$ is equal to $\underset{\cdot}{A}\,j^2$ and consequently,

$$\underset{\cdot}{B} = Cj^{\delta} - A\,j^{\alpha} \qquad (20)$$

$$= Cj^{\delta} + A\,j^{\alpha+2} \qquad (21)$$

where $\alpha^\circ = 90\,\alpha$ and $(\alpha + 2) = (\alpha^\circ + 180)$ deg.
Therefore according to equation (17) we get:

$$B^2 = C^2 + A^2 - 2\,AC\cos(\delta^\circ - \alpha^\circ) \qquad (22)$$

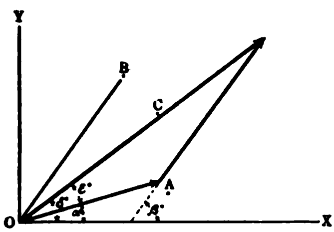


Fig. 2

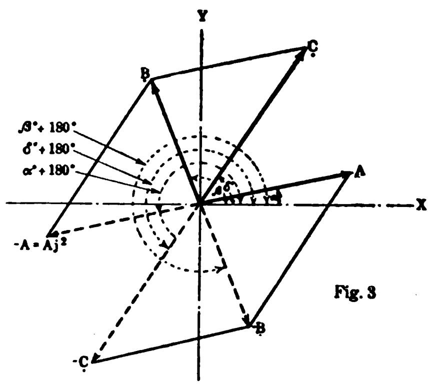


Fig. 3

The phase angle is given by:

$$\beta^\circ = \tan^{-1}\frac{C\sin\delta^\circ - A\sin\alpha^\circ}{C\cos\delta^\circ - A\cos\alpha^\circ} \qquad (23)$$

In this connection it may be noted further that, (see Fig. 3)

$$\underset{\cdot}{B} = \underset{\cdot}{C} - \underset{\cdot}{A} = Cj^{\delta} + A\,j^{(2+\alpha)} = (Cj^{(2+\delta)} + A\,j^{\alpha})\,j^2, \qquad (24)$$

or

$$\underset{\cdot}{B}\,j^{-2} = (\underset{\cdot}{C}j^2 + \underset{\cdot}{A}) = (\underset{\cdot}{A} - \underset{\cdot}{C}) \qquad (25)$$

4. *General Expression for Power.* The general expression for power which applies to a-c. or d-c. circuits of any wave shape and phase displacement is:

$$P = \frac{1}{T}\int_0^T eidt = \frac{1}{\pi}\int_0^{\pi} eid\,\theta \qquad (26)$$

where e and i are instantaneous values expressed as functions of the time, t, or the time angle, θ, and in the simplest case when e and i are constant, $P = EI$. If, however, e and i are given by a Fourier's series, products of harmonics of different frequencies will contribute nothing, and for the nth harmonic the power P_n will be given by:

$$P_n = \frac{1}{2} (E_{n\,max}\ I_{n\,max} \cos \alpha^\circ) = E_n\ I_n \cos \alpha^\circ \tag{27}$$

where E_n and I_n are the effective values of the nth harmonic of e. m. f., and current, and $\alpha^\circ = (90\ \alpha)$ deg. is the phase angle between E_n and I_n.

According to our notation if $\underset{\bullet}{E_n} = E_n\, j^\alpha$ and $\underset{\bullet}{I_n} = I_n$ then,

$$P_n = E_n\ I_n \cos \alpha^\circ$$

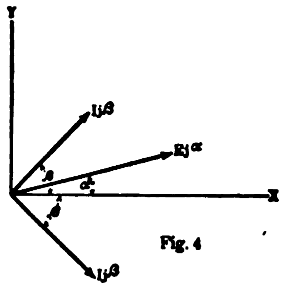


Fig. 4

If in general (see Fig. 4)

$$e = E_{max} \sin (\theta - \alpha) \tag{28'}$$

$$i = I_{max} \sin (\ \theta \pm \beta^\circ) \tag{29'}$$

or

$$\underset{\bullet}{E} = E j^\alpha \tag{28}$$

$$\underset{\bullet}{I} = I j^{\pm\beta} \tag{29}$$

where E and I represent the effective values of E_{max} and I_{max} and $\alpha^\circ = (90\ \alpha)$ deg. and $\beta^\circ = (90\ \beta)$ deg., the power P will be

$$P = \frac{1}{\pi} \int (ei)\, d\,\theta = \tfrac{1}{2}\ E_{max}\, I_{max} \cos (\alpha^\circ - \beta^\circ) \tag{30}$$

$$= E\, I \cos (\alpha^\circ \mp \beta^\circ) \tag{31}$$

where β may be positive or negative, *i. e.* whether the current be leading or lagging the power is given by equation **(31)**.

Comparing this result with the usual rectangular notation we have:

$$P = \frac{1}{\pi} \int (ei)\, d\,\theta = E_n\, I_n\, (\cos \alpha^\circ \cos\, \beta^\circ + \sin \alpha^\circ \sin\, \beta^\circ) \tag{32}$$

$$= ei \pm e'\, i' \tag{33}$$

where $\underset{\cdot}{E}_n = (e_n + je_n')$ and $\underset{\cdot}{I}_n = (i_n \pm ji_n')$

The general expression (**31**) is very simple and it states that the power in any circuit due to any harmonics of the same order is equal to the product of the r. m. s. value of voltage and current into the cosine of their (algebraic) phase difference. As to equation (**32**) it is seen that it can be translated into the general law that the power produced by a voltage $\underset{\cdot}{E} = (e + j\,e')$, and a current, $\underset{\cdot}{I} = (i \pm j\,i')$, is given by the real part of their product, with one important provision of *reversal of sign*. This change of sign impairs the simplicity of the rule although it may be accounted for by introducing the idea of double frequency quantities, etc.; however, this seems rather unnecessary and round about since it is not advisable to define average power as the product of two (plane) vectors, in the first place; it is best to base definitions on general and fundamental propositions.

5. *Logarithm of $A\,j^n$.* This is readily obtained by following the rules of algebra according to which:

$$\log\,(A\,j^n) = \log A + \log\,(j^n) \tag{34}$$

$$= \log A + n \log\,(j) \tag{35}$$

But the logarithm of any complex quantity $a + jb$ is known to be:

$$\log\,(a + jb) = \log\,(\sqrt{a^2 + b^2}) + j\,(\theta + 2\,\pi\, m) \tag{36}$$

where $\theta = \tan^{-1}\,(b/a)$ and m is any integer which for simplicity can be taken as zero. Consequently,

$$\log\,(j) = \log\,(j\,1) = j\left(\frac{\pi}{2} + 2\,\pi\, m\right) \tag{37}$$

and therefore:

$$\log\,(A\,j^n) = \log A + j\,\frac{\pi}{2}\,n \tag{38}$$

6. *Differentiation.* Assuming again that the operator j^n can be treated as an algebraic quantity we have:

$$d\,(\dot{A}) = d\,(A j^n = j^n . d\,(A) + A . d\,(j^n)$$

$$= j^n . d\,(A) + j^n \log\,(j) . dn \qquad (39)$$

Whence, substituting (37),

$$d\,(\dot{A}) = j^n . dA + \frac{\pi}{2}\, j^{(n+1)} . dn \qquad (40)$$

The same result can also be obtained as follows:

The differential of a complex quantity is known to be:

$$d\,(\dot{A}) = d\,(a + j\,a') = (\cos\theta . dA + A \sin\theta . d\theta)$$

$$+ j\,(\sin\theta . dA + A \cos\theta . d\theta) \qquad (41)$$

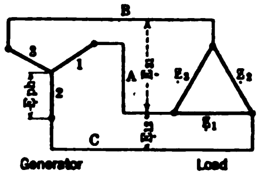


Fig. 5

It is easy, by substituting j^n for the operator $(\cos\theta + j \sin\theta)$, where $\theta = \frac{\pi}{2} n$, to obtain equation (40).

Or again, if desired the exponential form can be used and by substituting j^n for $e^{j\theta}$ in

$$d\,(A e^{j\theta}) = e^{j\theta} . dA + A\, e^{j\theta} j . d\theta \qquad (42)$$

expression (40) be derived.

III—Illustrative Problems

In order to illustrate the use and application of the method just described a few simple examples will be considered.

(1) A Y-connected generator feeds an unbalanced Δ-connected load as shown in Fig. 5. To find the respective phase and line currents, voltages, phase angles and power.

This problem will be solved by the use of complex quantities and the exponential form as follows:

A —Notation discussed above.

B —The usual reactangular form.

C —The usual polar form.

D —The exponential form.

Data:

Phase Voltages of Generator:

$$\begin{array}{llll}
\text{A} & \text{B} & \text{C} & \text{D} \\
\underset{\cdot}{E}_{1ph} = E_{ph} & = \begin{cases} e_{ph} \\ e_1 \end{cases} & = E_{ph1} & = E_{ph} \\
\underset{\cdot}{E}_{2ph} = E_{ph} j^{-\frac{4}{3}} & = \begin{cases} -0.5\, e_{ph} - j\, 0.866\, e_{ph} \\ e_2 + j\, e'_2 \end{cases} & = E_{ph}\left(\cos\dfrac{2\pi}{3} - j\sin\dfrac{2\pi}{3}\right) & = E_{ph}\, \epsilon^{-j\frac{2\pi}{3}} \\
\underset{\cdot}{E}_{3ph} = E_{ph} j^{-\frac{8}{3}} & = \begin{cases} -0.5\, e_{ph} + j\, 0.866\, e_{ph} \\ e_3 + j\, e'_3 \end{cases} & = E_{ph}\left(\cos\dfrac{4\pi}{3} - j\sin\dfrac{4\pi}{3}\right) & = E_{ph}\, \epsilon^{-j\frac{4\pi}{3}}
\end{array}$$

Impedances of Load:

$$\begin{array}{lll}
Z_1 j^{\alpha} = r_1 + j x_1 & = Z_1 (\cos \alpha' + j \sin \alpha') & = Z_1\, \epsilon^{j\alpha'} \\
Z_2 j^{\beta} = r_2 + j x_2 & = Z_2 (\cos \beta' + j \sin \beta') & = Z_2\, \epsilon^{j\beta'} \\
Z_3 j^{\gamma} = r_3 + j x_3 & = Z_3 (\cos \gamma' + j \sin \gamma') & = Z_3\, \epsilon^{j\gamma'}
\end{array}$$

where,

$$Z_1 = \sqrt{r_1^2 + x_1^2}; \quad \alpha^1 = \frac{\pi}{2}\, \alpha = \tan^{-1}\left(\frac{x_1}{r_2}\right)$$

Similarly for the others.

Solution:

Line voltages at load:

$$\begin{array}{llll}
\text{A} & \text{B} & \text{C} & \text{D} \\
\underset{\cdot}{E}_{12} = E j^{\frac{1}{3}} & = \begin{cases} e_{12} + j\, e'_{12} \\ 0.866\, E + j\, 0.5\, E \end{cases} & = E \left(\cos\dfrac{\pi}{6} + j\sin\dfrac{\pi}{6}\right) & = E\, \epsilon^{j\frac{\pi}{6}} \\
\underset{\cdot}{E}_{23} \quad E j^{-1} & = \begin{cases} -j\, e'_{23} \\ -j E \end{cases} & = E(-j) & = E\, \epsilon^{-j\frac{\pi}{2}} \\
\underset{\cdot}{E}_{31} = E j^{5/3} & = \begin{cases} e_{31} + j\, e'_{31} \\ -0.866\, E + j\, 0.5\, E \end{cases} & = E \left(\cos\dfrac{5\pi}{6} + j\sin\dfrac{5\pi}{6}\right) & = E\, \epsilon^{j\frac{5\pi}{6}}
\end{array}$$

where $E = \sqrt{3}\, E_{ph}$.

Phase currents of load:

$$\underset{\cdot}{I}_{1ph} = \frac{E}{Z_1} j^{(\frac{1}{3} - \alpha)} = \frac{(e_{12} + j\, e'_{12})\,(r_1 - j\, x_1)}{Z_1^2}$$

$$= \frac{E}{Z_1}\left[\cos\left(\frac{\pi}{6} - \alpha'\right) + j \sin\left(\frac{\pi}{6} - \alpha'\right)\right] = \frac{E}{Z_1}\epsilon^{j\left(\frac{\pi}{6} - \alpha'\right)}$$

$$\underset{\cdot}{I}_{2ph} = \frac{E}{Z_2} j^{-(1+\beta)} = \frac{(-j\, e'_{23})\,(r_2 - j\, x_2)}{Z_2^2}$$

$$= \frac{E}{Z_2}\left[-\sin\beta' + j\cos\beta'\right] = \frac{E}{Z_2}\epsilon^{-j\left(\frac{\pi}{2} + \beta'\right)}$$

$$\underset{\cdot}{I}_{3ph} = \frac{E}{Z_3} j^{(5/3 - \gamma)} = \frac{(e_{31} + j\, e'_{31})\,(r_3 - j\, x_3)}{Z_3^2}$$

$$= \frac{E}{Z_3}\left[\cos\left(\frac{5\pi}{6} - \gamma'\right) + j\sin\left(\frac{5\pi}{6} - \gamma'\right)\right] = \frac{E}{Z_3}\epsilon^{j\left(\frac{5\pi}{6} - \gamma'\right)}$$

Line Currents A

$$\underset{\cdot}{I}_A = (\underset{\cdot}{I}_{1ph} - \underset{\cdot}{I}_{3ph})$$

$$= j^{\delta}\left[I^2_{1ph} + I^2_{3ph} - 2\, I_{1ph}\, I_{3ph} \cos\left(\frac{5\pi}{6} - \gamma' - \frac{\pi}{6} + \alpha'\right)\right]^{\frac{1}{2}}$$

$$\underset{\cdot}{I}_B = (\underset{\cdot}{I}_{3ph} - \underset{\cdot}{I}_{2ph})$$

$$= j^{\theta}\left[I^2_{2ph} + I^2_{3ph} - 2\, I_{2ph}\, I_{3ph} \cos\left(\frac{5\pi}{6} - \gamma' + \frac{\pi}{2} + \beta'\right)\right]^{\frac{1}{2}}$$

$$\underset{\cdot}{I}_C = (\underset{\cdot}{I}_{2ph} - \underset{\cdot}{I}_{1ph})$$

$$= j^{\lambda}\left[I^2_{1ph} + I^2_{2ph} - 2\, I_{1ph}\, I_{2ph} \cos\left(\frac{\pi}{6} - \alpha' + \frac{\pi}{2} + \beta'\right)\right]^{\frac{1}{2}}$$

B.

$$\underset{\cdot}{I}_A = (\underset{\cdot}{I}_{1ph} - \underset{\cdot}{I}_{3ph}) = (i_{1ph} - i_{3ph}) + j\,(i'_{ph} - i'_{3ph})$$

$$\underset{\cdot}{I}_B = (\underset{\cdot}{I}_{3ph} - \underset{\cdot}{I}_{2ph}) = (i_{3ph} - i_{2ph}) + j\,(i'_{3ph} - i'_{2ph})$$

$$\underset{\cdot}{I}_C = (\underset{\cdot}{I}_{2ph} - \underset{\cdot}{I}_{1ph}) = (i_{2ph} - i_{1ph}) + j\,(i'_{2ph} - i'_{1ph})$$

where,

$$(i_{1ph} + j\, i'_{1ph}) = [(e_{12}\, r_1 + e'_{12}\, x_1) + j\, (e'_{12}\, r_1 - e_{12}\, x_1)]\, Z_1^{-2}$$

$$(i_{2ph} + j\, i'_{2ph}) = [-\, e'_{23}\, x_2 + j\, e'_{23}\, r_2]\, Z_2^{-2}$$

$$(i_{3ph} + j\, i_{3ph}) = [(e_{31}\, r_3 + e_{31}\, x_3) + j\, (e'_{31}\, r_3 - e_{31}\, x_3)]\, Z_3^{-2}$$

C.

$$\underset{\bullet}{I}_{A} = \left[\frac{E}{Z_1} \cos\left(\frac{\pi}{6} - \alpha'\right) - \frac{E}{Z_3} \cos\left(\frac{\pi}{6} - \gamma'\right)\right]$$

$$+ j\left[\frac{E}{Z_1} \sin\left(\frac{\pi}{6} - \alpha'\right) - \frac{E}{Z_3} \sin\left(\frac{5\,\pi}{6} - \gamma'\right)\right]$$

$$\underset{\bullet}{I}_{B} = \left[\frac{E}{Z_3} \cos\left(\frac{5\,\pi}{6} - \gamma'\right) - \frac{E}{Z_2} \sin\, \beta'\right]$$

$$+ j\left[\frac{E}{Z_3} \sin\left(\frac{\pi}{6} - \gamma'\right) + \frac{E}{Z_2} \cos\, \beta'\right]$$

$$\underset{\bullet}{I}_{C} = \left[\frac{E}{Z_2} \sin\, \beta' - \frac{E}{Z_1} \cos\left(\frac{\pi}{6} - \alpha'\right)\right]$$

$$- j\left[\frac{E}{Z_2} \cos\, \beta' + \frac{E}{Z_1} \sin\left(\frac{\pi}{6} - \alpha'\right)\right]$$

In case of method D in order to carry on actual computation it is necessary to make recourse to one of the other methods.

In regard to the expression given under B and C, it may be noted that the square root of the sums of the squares of the two components has to be taken in order to find the magnitude of the line currents I_A, I_B and I_C.

Phase angles of the line currents: A.

$$\delta^\circ = \tan^{-1} \frac{I_{1ph} \sin\left(\frac{\pi}{6} - \alpha'\right) - I_{3ph} \sin\left(\frac{5\,\pi}{6} - \gamma'\right)}{I_{1ph} \cos\left(\frac{\pi}{6} - \alpha'\right) - I_{3ph} \cos\left(\frac{5\,\pi}{6} - \gamma'\right)}$$

$$\theta^\circ = \tan^{-1} \frac{I_{3ph} \sin\left(\frac{5\pi}{6} - \gamma'\right) + I_{2ph} \sin\left(\frac{\pi}{2} + \beta'\right)}{I_{3ph} \cos\left(\frac{5\pi}{6} - \gamma'\right) - I_{2ph} \cos\left(\frac{\pi}{2} + \beta'\right)}$$

$$\lambda^\circ = \tan^{-1} \frac{-I_{2ph} \sin\left(\frac{\pi}{2} + \beta'\right) - I_{1ph} \sin\left(\frac{\pi}{6} - \alpha'\right)}{I_{2ph} \cos\left(\frac{\pi}{2} + \beta'\right) - I_{1ph} \sin\left(\frac{\pi}{6} - \alpha'\right)}$$

where $\delta^\circ = 90\,\delta$ degrees, and similarly for the others.

B

$$\delta^\circ = \tan^{-1} \frac{i'_{1ph} - i'_{3ph}}{i_{1ph} - i_{3ph}} \qquad \theta^\circ = \frac{i'_{3ph} - i'_{2ph}}{i_{3ph} - i_{2ph}}$$

$$\lambda^\circ = \tan^{-1} \frac{i'_{2ph} - i_1{}'_{ph}}{i_{2ph} - i_{1ph}}$$

C

$$\delta^\circ = \tan^{-1} \frac{\frac{E}{Z_1} \sin\left(\frac{\pi}{6} - \alpha'\right) - \frac{E}{Z_3} \sin\left(\frac{5\pi}{6} - \gamma'\right)}{\frac{E}{Z_1} \cos\left(\frac{\pi}{6} - \alpha'\right) - \frac{E}{Z_3} \cos\left(\frac{5\pi}{6} - \gamma'\right)}$$

similarly for θ° and λ°.

Power at the load: A

$$P_{1ph} = I^2{}_{1ph} Z_1 \cos\alpha^\circ \text{ or } P_{1ph} = E I_{1ph} \cos(30^\circ - \alpha^\circ - 30^\circ)$$

$$P_{2ph} = I^2{}_{2ph} Z_2 \cos\beta^\circ \text{ or } P_{2ph} = E I_{2ph} \cos(-150^\circ - \beta^\circ - 150^\circ$$

$$P_{3ph} = I^2{}_{3ph} Z_3 \cos\gamma^\circ \text{ or } P_{3ph} = E I_{3ph} \cos(150^\circ - \gamma^\circ - 150^\circ)$$

B

$$P_{1ph} = I^2{}_{1ph}\, r_1 \text{ or } P_{1ph} = e_{12}\, i_{1ph} + e'_{12ph}\, i'_{1ph}.$$

$$P_{2ph} = I^2{}_{2ph}\, r_2 \text{ or } P_{2ph} = -\, e'_{23}\, i'_{2ph}$$

$$P_{3ph} = I^2{}_{3ph}\, r_3 \text{ or } P_{3ph} = e_{31}\, i_{3ph} + e'_{31}\, i'_{1ph}$$

C and D

$$P_{1ph} = \frac{E^2}{Z_1} \cos \alpha^\circ \quad P_{2ph} = \frac{E^2}{Z_2} \cos \beta^\circ \quad P_{3ph} = \frac{E^2}{Z_3} \cos \gamma^\circ$$

which are, of course, similar to the expression given for method A.

Numerical example: Let $E = 100$; $E_{ph} = \dfrac{100}{\sqrt{3}}$;

$$\begin{aligned} \text{and, } Z_1 &= 1.\ j^{\frac{45^\circ}{90^\circ}} & & 0.707 + j\,0.707 \\ Z_2 &= 1.2\,j^{\frac{20^\circ}{90^\circ}} & &= 1.128 + j\,0.408 \\ Z_3 &= 1.3\,j^{\frac{-10^\circ}{90^\circ}} & &= 1.28 - j\,0.226 \end{aligned}$$

then,

$$I_{1ph} = 100\,j^{\frac{-15^\circ}{90^\circ}} \qquad I_{2hh} = 83.3\,j^{\frac{-110^\circ}{90^\circ}} \qquad I_{3ph} = 77\,j^{\frac{160^\circ}{90^\circ}}$$

$$I_A = [\overline{100}^2 + \overline{77}^2 - 200 \times 77 \cos 175^\circ]^{\frac{1}{2}} = 177 \text{ amperes.}$$

$$I_B = [\overline{83.3}^2 + \overline{77}^2 - 2 \times 83.3 \times 77 \cos 270^\circ]^{\frac{1}{2}} = 114 \text{ amperes.}$$

$$I_C = [\overline{83.3}^2 + 100^2 - 200 \times 83.3 \cos 95^\circ]^{\frac{1}{2}} = 137 \text{ amperes.}$$

$$\delta^\circ = 18^\circ = \delta\,(90^\circ);\ \delta = 0.2$$

$$\theta^\circ = 112.8^\circ = \theta\,(90^\circ);\ \theta = 1.255$$

$$\lambda^\circ = 202.8^\circ = \lambda\,(90^\circ)\lambda = 2.259$$

Power at load:

$$\begin{aligned} P_1 &= 100 \times 100 \times \cos 45^\circ \\ &= 1 \times \overline{100}^2 \times \cos 45^\circ & &= 7070 \text{ watts} \end{aligned}$$

$$\begin{aligned} P_2 &= 100 \times 83.4 \times \cos 20^\circ \\ &= \overline{83.4}^2 \times 1.12 \times \cos 20^\circ & &= 7860 \text{ watts} \end{aligned}$$

$$\begin{aligned} P_3 &= 100 \times 77 \times \cos 10^\circ \\ &= \overline{77}^2 \times 1.3 \times \cos 10^\circ & &= 7600 \text{ watts} \end{aligned}$$

Total power at load $= 22{,}520$ watts.

Power at generator:

$$P_1 = 177 \times \frac{100}{\sqrt{3}} \times \cos 18^\circ = 9710.$$

$$P_2 = 114 \times \frac{100}{\sqrt{3}} \times \cos 120^\circ = 6520.$$

$$P_3 = 137 \times \frac{100}{\sqrt{3}} \times \cos 240^\circ = 6290.$$

Total power at generator = 22,520 watts.

The vector diagram is shown in Fig. 6.

2. A load having a variable power factor and consuming a constant voltage is supplied through an inductive line whose characteristics are: $(r + jx) = \dot{Z} = Z j^{\alpha}$. To investigate the effect of leading and lagging current on the generator voltage.

Taking the load voltage as the reference vector, the generator voltage, E_g, is:

$$E_g = e + I j^{\pm\beta} . Z j^{\alpha} = e + IZ j^{(\alpha \pm \beta)}$$

where the positive sign refers to leading and the negative sign to lagging current.

Inasmuch as we are dealing with vector addition of a quantity (IZ), making $(\alpha^\circ \pm \beta^\circ)$ degrees with a horizontal line (e) volts, a little consideration will show that for any given value of β° the resultant E_g will be larger when β° is negative, *i. e.* when the load is inductive than when the load is condensive. Indeed it is not difficult to form a mental picture of the sum of the two vectors, e and $(IZ) j^{(\alpha \pm \beta)}$, and see that when $(\alpha^\circ \pm \beta^\circ) = 0$, E_g is maximum, and when

$$(\alpha^\circ \pm \beta^\circ) = 90^\circ \; E_g \text{ is minimum.}$$

Suppose now we prove this elementary but fundamental proposition by means of the usual rectangular form of complex quantities:

$$E_g = [(e + ir - i'x)^2 + (i'r + ix)^2]^{\frac{1}{2}}, \text{ for leading current.}$$

$$E'_g = [(e + ir + i'x)^2 + (ix - i'r)^2]^{\frac{1}{2}} \text{ for lagging current.}$$

It is not apparent by comparing these equations to see whether $E_g > E_g'$ or vice-versa.

3. Finally consider the calculation of the characteristics of a long transmission line with distributed inductance and capacity. It is known that the voltage and current at any point along the line, at a distance l from the receiving end, are given by the following expressions:

$$\underset{\cdot}{E}_1 = \underset{\cdot}{E}_r\ (1 + \underset{\cdot}{Z}\underset{\cdot}{Y}/2 + \underset{\cdot}{Z}^2\underset{\cdot}{Y}^2/24) + \underset{\cdot}{Z}\underset{\cdot}{I}_r\ (1 + \underset{\cdot}{Z}\underset{\cdot}{Y}/6 + \underset{\cdot}{Z}^2\underset{\cdot}{Y}^2/120)\ ..$$

$$\underset{\cdot}{I}_1 = \underset{\cdot}{I}_r\ (1 + \underset{\cdot}{Z}\underset{\cdot}{Y}/2 + \underset{\cdot}{Z}^2\underset{\cdot}{Y}^2/24) + \underset{\cdot}{Y}\underset{\cdot}{I}_r\ (1 + \underset{\cdot}{Z}\underset{\cdot}{Y}/6 + \underset{\cdot}{Z}^2\underset{\cdot}{Y}^2/240)\ ..$$

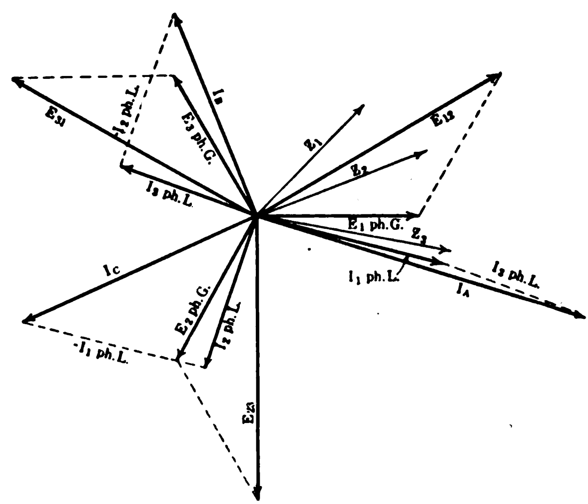


Fig. 6

Generator voltages, E_1, *ph. G.* etc., line voltages, E_{12}, etc. are to same scale. Phase currents of load, I_1*ph L.* etc., and line currents, I_A etc. are to same scale which is different from the voltage scale.

where Z and Y are the impedance and admittance of the length of the line under consideration, and the subscript refers to the receiving end. These equations are fairly long for purposes of calculation on account of the many multiplications involved furthermore computations become rather tedious owing to the fact that ordinarily, either the real or imaginary components of some of the quantities involved are very small, but still cannot be neglected. These objections will remain true, although to a lesser degree, even when the equations are simplified by dropping the terms containing Z^2 and Y^2. For the sake of comparison the

e. m. f. equation is given in the usual notation and in the one discussed above:

$$\dot{E}_1 = (e_r + je'_r)\,[1 + (r + jx)\,(g + jb)/2 + (r + jx)\,(i_r + ji_r')]$$

$$E_1 = E_r j^{\delta} + E_r Z Y j^{(\alpha + \beta + \delta)} + I_r Z j^{(\alpha + \gamma)}$$

As an example the curves in Fig. 7 give the characteristics of a transmission line 100 miles long and delivering 20,000 kw. at 100 kv. (or $100/\sqrt{3}$ to neutral) with a periodicity of 25 cycles per second. The line consists of two No. 00 B. & S. aluminum conductors in parallel, spaced 7 ft. apart and strung on separate steel towers. The resistance is 32.2 ohms, the inductive react-

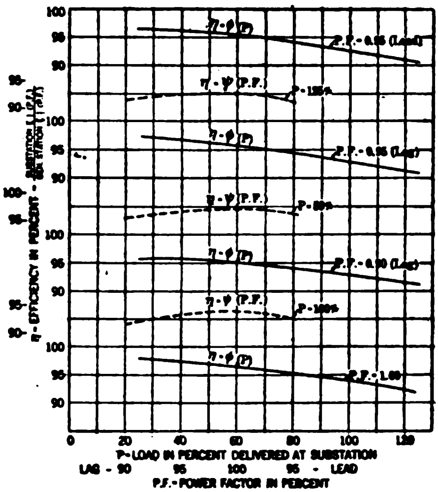


Fig. 7

ance is 4376 ohms and the condensive reactance is 0.664 ohms per conductor.

The calculations are too lengthy to be given in detail and would be of little value since nothing can take the place of testing for ones' self, by actual calculations, the advantages and disadvantages of the different methods.

IV—Critical Resume and Summary

It has been shown that without any radical modification of the present day method of alternating current technology it is possible to deal in *calculations* directly with vectors in a simple manner by using the polar form of complex quantities involving

the operator $j^{\alpha} = (\sqrt{-1})^{\alpha}$, which indicates rotation through $90\ \alpha$ deg. in the positive direction. Thus,

$$\underset{\bullet}{E} = Ej^{\alpha}\text{, in the polar form given herein;}$$

$$\underset{\bullet}{E} = e + je'\text{, in the rectangular form.}$$

The choice of mathematical methods and notations is necessarily to a certain extent, influenced by personal tastes and it is not practicable to give any general rules as to when the notation given herein, either by itself or in combination with others, will prove most advantageous. At present some engineers prefer to use trigonometric methods entirely, while others employ complex quantities almost exclusively; still others use either of these methods or exponentials and hyperbolic functions, etc. according to whichever they think lends itself best to the case under consideration. Although the last ones are probably in the minority, it is no doubt best to avail oneself of the peculiar advantages of the different notations so far developed.

The judicious choice of either the rectangular or polar form of complex quantities as given here and the judicious combination of the same in dealing with alternating current problems will be found useful in the theory and calculation of alternating currents and alternating current machinery.

For convenience of reference the summary below is given:

I. A sinusoidal or equivalent sinusoidal function may be represented by means of one of the following notations:[2]

$$(1)\quad \underset{\bullet}{A} = A\,j^{\alpha}$$

$$(2)\quad \underset{\bullet}{A} = a + ja'$$

$$(3)\quad \underset{\bullet}{A} = A\,(\cos\alpha^{\circ} + j\sin\alpha^{\circ})$$

$$(4)\quad \underset{\bullet}{A} = A\,e^{j\alpha'}$$

$$(5)\quad \underset{\bullet}{A} = A\underline{/\alpha^{\circ}}$$

Where $\frac{\pi}{2}\,\alpha = \alpha'$ radians and $\alpha\ 90 = \alpha^{\circ}$ deg.

2. The exponent of j in (1) is a number; the exponent of (4) must be j (radians); and the angle in (3) and (5) may be expressed in radians or degrees. In this connection it may be noted that (5) is more of a ***symbol*** than a ***mathematical nota'ion.***

II. The product of any number of vectors is:

$$\underset{\cdot}{B} = \underset{\cdot}{A}\underset{\cdot}{B}\underset{\cdot}{C} \text{ etc.} = (ABC \text{ etc.})\,\left(j^{(\alpha + \beta + \gamma \text{ etc.})}\right)$$

III. The quotient of any number of vectors is:

$$\frac{\underset{\cdot}{A}\underset{\cdot}{B} \text{ etc.}}{\underset{\cdot}{C}\underset{\cdot}{D} \text{ etc.}} = \frac{AB \text{ etc.}}{CD \text{ etc.}}\; j^{(\alpha + \beta \text{ etc.}) - (\gamma + \delta \text{ etc.})}$$

The reciprocal of a vector Zj^{α} is $(I/Z)\,j^{-\alpha}$

IV. The sum of two vectors is:

$$A\,j^{\alpha} + B\,j^{\beta} = [A^2 + B^2 + 2\,AB \cos(\alpha^{\circ} - \beta^{\circ})]^{\frac{1}{2}}\,j^{\delta}$$

where,

$$\delta^{\circ} = \tan^{-1}\frac{A \sin\alpha^{\circ} - B \sin\beta^{\circ}}{A \cos\alpha^{\circ} - B \cos\beta^{\circ}} = (90\delta) \text{ and } \alpha^{\circ} = (\alpha\,90);$$

$$\beta^{\circ} = (\beta\,90)$$

V. The difference of two vectors is:

$$Aj^{\alpha} - B\,j^{\beta} = [A^2 + B^2 - 2\,AB \cos(\alpha^{\circ} - \beta^{\circ})]^{\frac{1}{2}}\,j^{\delta}$$

where,

$$\delta^{\circ} = \tan^{-1}\frac{A \sin\alpha^{\circ} - B \sin\beta^{\circ}}{A \cos\alpha^{\circ} - B \cos\beta^{\circ}}$$

VI. The power in a circuit due to a current $Ij^{\pm\beta}$ propelled by an e.m.f. $E\,j^{\alpha}$ is:

$$P = EI \cos(\alpha^{\circ} - \beta^{\circ})$$

VII. The differential of Aj^{α} is:

$$d\,(A\,j^{\alpha}) = j^{\alpha}\,(dA + A\,j\,\frac{\pi}{2}\,.\,d\,\alpha)$$

VIII. The logarithm of $A\,j^{\alpha}$ is:

$$\log(A\,j^{\alpha}) = \log A + j\left(\frac{\pi}{2}\;\alpha + 2\,\pi\,m\right)$$

where m may be taken as zero.

IX. Some other expressions of interest are as follows:

1. $\dot{A} = A\, j^{\alpha}$ or strictly $\dot{A} = A\, j^{\alpha+4m}$, where m may be taken as zero, this being the usual practice in all similar cases. For instance, $1/2 = \sin \pi/6$ or strictly $1/2 = \sin (\pi/6 + 2\,\pi\, m)$

2. $(Aj^{\alpha})^m = A^m\,(j^{m\alpha})$. Similarly,

$$\sqrt[m]{Aj} = A^{1/m}.j^{\alpha/m}$$

3. $j^{\alpha} = e^{j\,\alpha\frac{\pi}{2}} = (\cos \alpha^{\circ} + j \sin \alpha^{\circ})$, where $(\alpha \times 90) = (\alpha^{\circ})$ deg.

Therefore, $j = \sqrt{-1} = e^{j\,\pi/2}$

4. $$\log j = \log\,(e^{j\,\pi/2}) = j\,\frac{\pi}{2}$$

$$\log j^{\alpha} = \log\,(e^{j\,\alpha\,\pi/2}) = j\,\alpha\,\frac{\pi}{2}$$

In conclusion the writer wishes to thank Mr. W. C. Graustein, of the department of mathematics of the Rice Institute, for valuable criticisms and suggestions.

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TRACTIVE RESISTANCES TO A MOTOR DELIVERY WAGON ON DIFFERENT ROADS AND AT DIFFERENT SPEEDS

BY A. E. KENNELLY AND O. R. SCHURIG

ABSTRACT OF PAPER

In this paper is given a complete report on an investigation of tractive resistances of urban roads to a motor delivery wagon equipped with solid rubber tires. The "tractive resistance" as used in this paper, includes still-air resistance, but does not include wind resistance and the resistances internal to the truck. The test truck is fully described with its driving mechanism and the storage battery which supplied the motive power. The investigation involved test runs over definite lengths of road, at measured truck speeds, to determine the gross battery output during these runs; and laboratory tests to determine the overall efficiency of the truck between battery terminals and rear-wheel treads at speeds and loads corresponding to the road tests. The results included in the paper are (1) overall efficiency of truck mechanism and (2) tractive resistances of a number of typical urban roads. The components of tractive resistance for a typical road are also given.

THE INVESTIGATION herein described was carried on in the Research Division of the Electrical Engineering Department, at the Massachusetts Institute of Technology, during the year 1915, under a fund contributed for researches on motor trucks.

Object of the Research. The object of this research was to determine the resistance, including air resistance, offered to an electric truck, by level urban roads of different surface varieties, at standard truck speeds not exceeding 25 km. (15.5 miles) per hour. For this purpose, the output of the storage battery on a test truck was measured, for both directions of travel, over standard road beds, at different controller speeds. From this output were deducted all the corresponding electrical and mechanical losses in the truck mechanism, as determined by laboratory tests. The remainder of the output was consequently attributed to (1) road- (2) air- and (3) wind-resistance. The wind resistance was eliminated by averaging the results for

Manuscript of this paper was received April 14, 1916.

both directions of running, leaving as the final result the sum of the road and air resistances.

By "road resistance" is meant the horizontal force required to pull the truck, assumed as internally frictionless, over the horizontal road, in the absence of air. By "air resistance" is meant the horizontal force on the truck required to overcome the resistance of the air, assumed as quiescent in the absence of the truck. By "wind resistance" is meant the horizontal force on the truck necessary to overcome the resistance of the wind velocity, or that velocity of the air with respect to the ground which exists in the absence of the truck.

The Test Truck

Through the courtesy of the manufacturer, a 1000-lb. (450-kg.) worm-drive, single-reduction electric truck, or delivery wagon, was placed at the disposal of the Research Division for the purposes of the test. A picture of this truck is given in Fig. 1. Its specifications are as follow:

Load capacity 1000 lb. (450 kg.) equipped with one d-c. series motor.

Overall length of frame	4280 mm.	168½ in.
Width of frame	890 mm.	35 in.
Wheel base (*i. e.* distance between centers of front and rear wheels, when front and rear axles are parallel)	2730 mm.	107⅜ in.
Wheel gage	1470 mm.	58 in.

The total weight of the truck, including motor, battery and body, but without load or passengers, was 4200 lb. (1910 kg.). Each of the four wheels was equipped with one solid-rubber demountable tire (manufactured for this type of delivery wagon) rated at 36 in. by 2½ in. (91.5 cm. by 6.35 cm.), and actually measuring about 35 in. (89 cm.) tread diameter, and 2½ in. (6.35 cm.) width of base. The brakes were of the internal expanding type on each rear wheel.

A cross section of the rear wheel, showing bearings and tire, is seen in Fig. 2. Fig. 3 is a drawing of side and front elevations of the truck. This type of electric truck is commonly used for city and suburban parcel-delivery service.

The transmission system was of the shaft type, the speed reduction between motor and rear wheels being accomplished by a single worm with worm wheel, *i. e.*, the motor shaft is extended, through two universal joints, *U* (Fig. 3), which allow for spring compression due to load and impact, to the worm *W* (Fig. 4). Through *W*, the rotation is transmitted to the worm-

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FIG. 1—VIEW OF TEST TRUCK

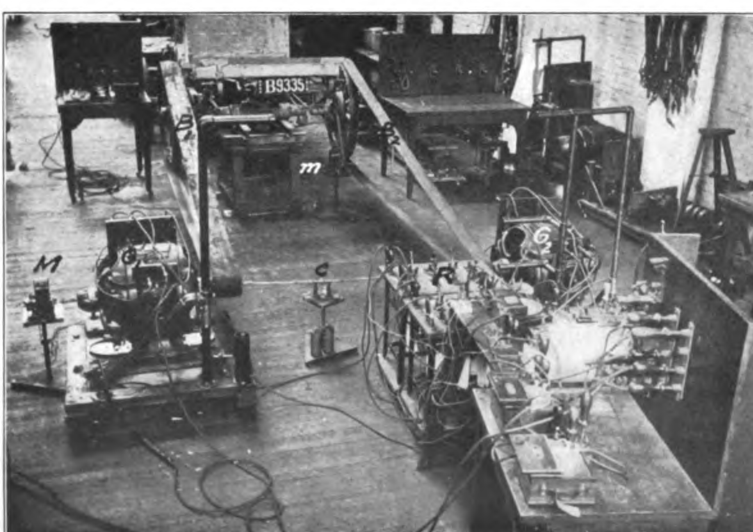

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FIG. 8—VIEW OF TEST ARRANGEMENT FOR TRUCK EFFICIENCY

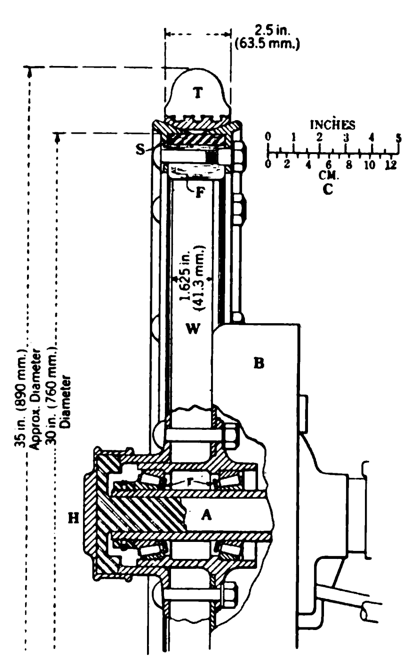

FIG. 2—CROSS-SECTION OF REAR-WHEEL BEARING WITH WHEEL AND TIRE

T demountable solid-rubber motor tire, rated at 36 in. by 2½ in. (915 mm. by 63.5 mm.)
S steel band
F bent felloe
W wheel with 12 spokes
B brake drum, containing internal-expanding brake (details not shown).
r tapered roller bearings
H hub cap
A rear-wheel axle
C approximate scale.

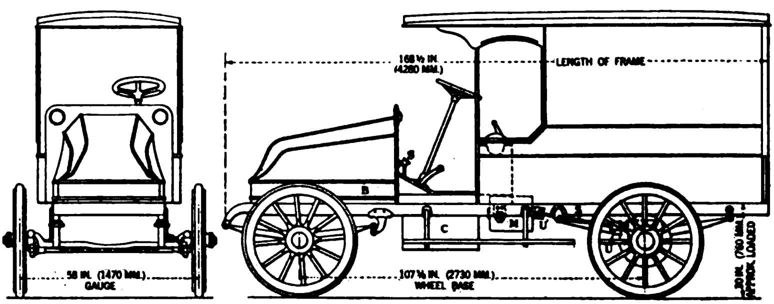

FIG. 3—SIDE AND FRONT ELEVATIONS OF TEST VEHICLE

B Battery compartment containing 45 cells
C Battery compartment containing 15 cells.
M Truck motor
UU Universal joints
S Driving shaft connecting motor and worm gear
s Speedometer

wheel *R*, (Fig. 4), which makes one revolution for every nine of the worm, or of the motor. In order to transmit the motive power to both wheels, and yet permit them to revolve at different speeds, the differential gear is provided, which consists

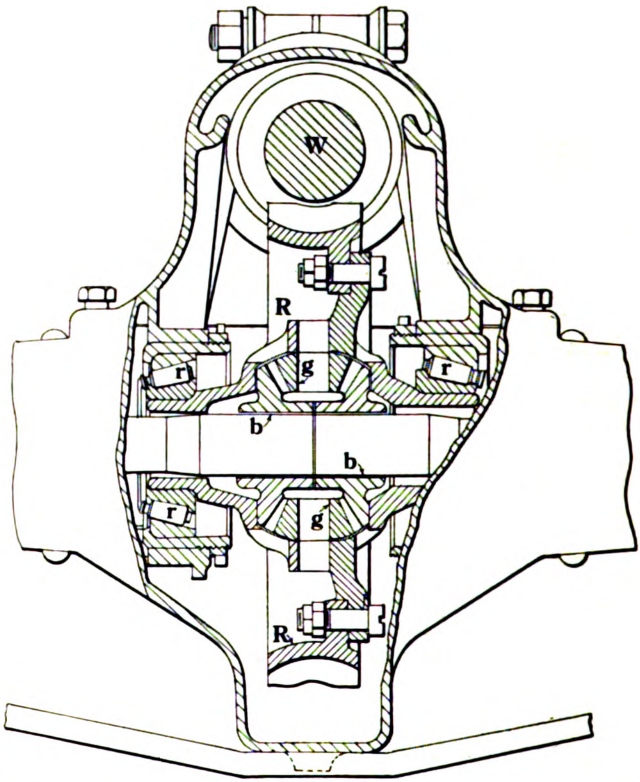

FIG. 4—SECTION THROUGH DIFFERENTIAL GEAR FOR WORM-DRIVE TRUCK

W worm
R worm wheel; ratio of worm to worm-wheel = 9:1
gg gears attached to worm-wheel *R*
bb bevel gears meshing with *gg* and connected to sections of rear-wheel shaft
rr tapered roller bearings

of the small bevel gears *gg*, capable of revolving about axes fixed to the worm wheel *R*; the small gears *gg* mesh with the two bevel gears *bb*, of which one is fixed to the right-hand section, and the other to the left-hand section of the rear axle. The corresponding shaft bearings of the roller-bearing type are *rr*.

Driving Motor and Controller. The electric motor *M*, Fig. 3, has the following specification: No. 282,666, E20, W 2, 32 amperes, 60 volt, 1200 rev. per min. The manufacturer's test data for this type of motor are given in Fig. 5.

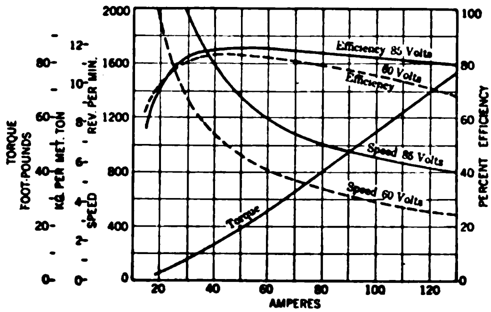

FIG. 5—MANUFACTURERS' CHARACTERISTIC CURVES FOR AUTOMOBILE MOTOR

60-volts—32 amperes—1200 rev. per min.—the two series field windings are connected in parallel with each othei

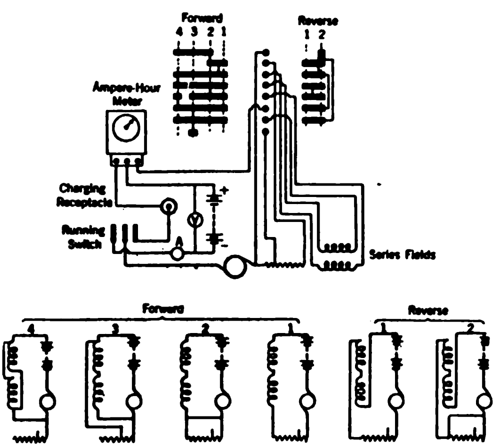

FIG. 6—DEVELOPMENT OF CONTROLLER AND DIAGRAM OF CIRCUIT CONNECTIONS

The controller is of the following description: Type S-35, Form A. It is of the drum type, having four forward and two reverse speeds.

The connection diagram of the controller and motor is given in Fig. 6.

The operation of the controller is as follows:

*Forward, point 1. Fields 1 and 2 in series, all starting resistance in series with armature and fields.

*Forward, point 2. Fields 1 and 2 in series, all starting resistance short circuited.

Forward, point 3. Fields 1 and 2 in series, but shunted by resistance R_2

Forward, point 4. Fields 1 and 2 in parallel, starting resistance not used.

Storage Battery. The battery consisted of 60 Type A-6 cells of the regular nickel-iron type, with a rated discharge capacity of 225 ampere-hours. The normal charge and discharge rate is 45 amperes, and the normal period of charge is seven hours

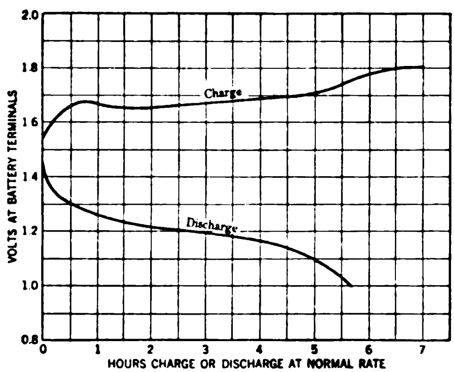

Fig. 7—Manufactures' Curves of Terminal Voltage per Cell during Charge and Discharge at Normal Rate for Alkaline Storage Battery

at this rate. Fig. 7 gives the manufacturer's curves of terminal voltage per cell during charge and during discharge, in each case at the normal rate of 45 amperes. The average discharge voltage per cell is approximately 1.2 volts. The battery was placed in two compartments, one being 23 in. by 18 in. (58 cm. by 46 cm.) and 15 in. (38 cm.) deep with 15 cells at *C*, Fig. 3; another being 40 in. by 31 in. (102 cm. by 79 cm.) and 15 in. (38 cm.) deep, with 45 cells at *B*, (Fig. 3.)

The entire battery with solution, trays and connections, weighs approximately 1200 lb. (550 kg.)

*Reverse, point 1, same as forward point 1, except that direction of current through series fields is reversed.

Reverse, point 2, same as forward point 2, except that direction of current through series fields is reversed.

Experimental Procedure

The tests made were of two kinds; namely,

(1) Road tests, over selected measured lengths of road, at different measured truck speeds, to determine the gross battery output.

(2) Laboratory tests, to determine the overall efficiency between battery terminals and rear-wheel treads, at speeds and loads corresponding to the road tests.

Road Tests. The resistance (excluding air-resistance) offered by a level roadbed to a moving truck, depends upon

(1) The surface quality; *i. e.*, the smoothness, hardness and resilience of the road surface.

(2) The size of wheel and tire quality; *i. e.*, the dimensions, smoothness, hardness and resilience of the tire tread.

(3) The speed of the vehicle.

(4) The load or weight of the vehicle.

(5) The construction of the vehicle, *i. e.*, whether with or without springs.

In these tests variations in (2) and (5) were eliminated, by using the same vehicle and the same type and size of wheel and tire throughout, which fairly represent standard average conditions for half-ton truck service.

In order to investigate the effects of road surface quality on tractive resistance, stretches of nearly level typical urban roads were selected, with the aid of records in the Boston City Engineers office. Runs were made with the truck over each selected stretch of road, at nearly constant speed by controller, and successively in both directions for each controller point, thus covering the range of speeds afforded by the controller. The effect of load in the vehicle, upon the tractive resistance, was also tried in a few cases.

The technique of the tests was as follows: Previous to the first test of the day, the car storage battery was fully charged. The car crew consisted of one driver and two observers. The driver confined his attention to steering the car, while running at constant controller position. If the driver had to change the controller position, or apply the brakes, during the run, the run was repeated.

The first observer was stationed on the front seat, beside the driver, and noted the stop-watch times of start and finish, as well as the readings of the speedometers during the run.

The second observer was stationed in the body of the truck,

and continuously took readings of voltage and current at battery terminals, by calibrated measuring instruments; these instruments being supported on cushions to minimize their vibration. The positions of these instruments in the battery circuit are indicated in Fig. 6 at A and V.

The start and finish for each stretch of road were marked off by chalk, or other clearly visible lines, drawn across the roadway. The car was always set in motion at a suitable distance behind the starting line, so as to reach approximately steady speed when this line was crossed. A stop-watch was started by the first observer at this moment. It was stopped by the same observer at the moment when the front wheels of the car crossed the finish line. The reading of the stop-watch was thus the time of the run.

The length of the run between start and finish lines was determined by means of a tape line. The runs varied in length from 400 ft. (120 m.) to 2600 ft. (790 m.)

Wherever the grades of the test stretches were not obtained from the city maps, they were measured directly, on special days, by the car observers, with surveyors' level and rod, in the regular way.

For each controller speed, the car was run three times in each direction, over the test section, in immediate succession. By this method of running in alternate directions over the same section, the effect of wind on car resistance was approximately eliminated, on the assumption that if a wind was blowing, it was uniform in velocity, and tended to exert a uniform pressure on the car, whether the latter was running with it or against it. No heavy windstorms occurred during the period selected for the tests. The arithmetical mean of the road resistances, as measured at nearly constant speeds in opposite directions, was assumed to eliminate the effect of wind velocity.

A further correction, namely that due to the change of kinetic energy inparted to the vehicle, between start and finish, became necessary, because the speed was not absolutely constant during the run; *i.e.*, a slight retardation or acceleration took place over the test stretch, in spite of the fact that the controller was not changed, that roads of uniform grade were selected, and also that the truck was started as far in advance of the mark as was practicable. The energy imparted to a truck which is accelerating includes not only that necessary to overcome its internal and external resistances, but also that definite amount

of energy which is required to produce the acceleration. The latter portion of energy is known to be equal to

$$\frac{1}{2}\ \frac{W}{g}(v_2^2 - v_1^2) \qquad \text{kg.-m.}$$

where W is the mass accelerated (kg.), v_2 and v_1 being the velocities in m. per sec. at end and at beginning of the run, respectively; g is the mean constant of acceleration due to gravity, *i.e.*, 9.81 m. per sec. This energy was substracted from the total energy imparted to the truck. The importance of this correction and the method of its application in a typical case may be seen from Table III.

Table I contains a sample set of observations made in a particular run in alternate directions over a test section.

Laboratory Tests. In order to determine the truck-mechanism overall efficiency, from storage-battery terminals to tire treads, as already referred to, the car was taken into the Lowell laboratory, the rear wheels raised from the ground, and belted each to a load-generator. The motor was then operated through the controller, at a number of speeds, the power being delivered to the load-generators and measured over a considerable range of speeds and outputs. Fig. 8 gives a photographic view of the test arrangement. The car B-9335 is shown, with its rear axle supported on I-beams. The rear wheels are belted to two similar 5 h.p. d-c. generators G_1G_2, loaded by banks of adjustable *Ia-Ia* resistors R. Fig. 9 gives a diagram of the electrical test connections.

The speed of the rear wheels, in these laboratory tests, was measured by means of the magneto m (Fig. 8), belted to one of the wheel brake drums. It was also checked by means of the magneto M coupled to one of the load generators G_1. In order to ensure equality in speeds of the two truck wheels, under test conditions, so that the load might be equally divided between them, and that the conditions might correspond to those when the car runs on a straight path, a slip counter c was inserted between the two generator shafts, so as to indicate, by the flashing of a light, if their speeds materially differed.

The load generators were separately excited. Their output was measured by d-c. voltmeter V, and ammeters A_1A_2, Fig. 9, in their respective circuits. Separate tests were made on the load generators G_1 G_2, to determine their mechanical and electrical armature losses, under different load conditions. These

TABLE I.

SAMPLE SET OF OBSERVATIONS FOR TYPICAL TEST RUN

Run No. 19. *Length* 900 ft. (274 m.) *Gross Weight* 4710 lb. (2140 kg.) *Date* June 15. 1915.
Location = Beacon St., Brookline, Mass.
Start = (east) mark in curb at crossing of Kilsyth St., Elevation: 0
Finish = (west) " " " " Strathmore Road, " +4.3 ft. (1.31 m.)
Description = tar macadam, in good condition, surface wet.
Weather = cloudy, misty rain; wind east; temp. 60 deg. fahr. (15.5 deg. cent.)

Controller Point 1.

	1st Run						2nd Run						3rd Run					
Time	63.6 sec.			51.0 sec.			63.0 sec.			51.4 sec.			62.4 sec.			53.6 sec.		
Direction	West			East			West			East			West			East		
	Battery output		†km per hr.	Battery output		†km per hr.	Battery output		†km. per hr.	Battery output		†km. per hr.	Battery output		†km per hr.	Battery output		†km. per hr.
	volts	amp.		volts	amp.		volts	amp.		volts	amp.		volts	amp.		volts	amp.	
	80	29.5	16.3	81	22.5	19.1	79	28.5	16.3	80	23.0	18.3	81	27.5	18.1	80.5	24.8	18.0
	80	30.1	15.6	81	21.5	21.1	79	29.0	15.9	80	22.5	20.1	81	28.5	16.6	80.5	24.0	18.7
	79.5	30.1	15.3	81	22.5	19.7	79	28.5	15.9	80	22.5	19.7	80	29.5	15.1	80.5	23.8	18.2
	79.5	29.5	15.6	81	23.0	19.1	79	29.5	15.9	80	22.5	19.1	80	29.5	16.1	80	24.0	19.1
	79.5	28.5	15.3	81	23.0	21.1	79.5	29.5	15.6	80	22.5	18.6	79.5	30.1	15.3	80	23.8	18.7
	79.5	29.5	15.3	81.5	22.5	18.7	79.5	29.0	15.3	81	23.8	19.7	79.5	30.8	15.3	80	23.8	18.0
	79	30.1	15.7	....	....	19.1	79.5	28.5	15.3	81	22.5	19.7	79.5	29.5	15.3	80.5	23.0	19.1
	....	....	15.3	....	....	19.1	79.5	29.0	15.6	81	22.0	....	79.5	29.5	15.3	80.5	23.0	....
	....	....	15.3	....	....	19.1	79.5	29.0	15.6	81	22.0	....	....	....	....	....	....	....
	....	....	14.7	....	....	....	78.5	29.5	15.6	81	22.0	....	....	....	....	....	....	....
	....	....	....	....	....	....	78.5	30.8	15.3	....	....	....	....	....	....	....	....	....
Averages	2360 watts		15.4 15.5*	1830 watts		19.6 19.4*	2310 watts		15.7 15.7*	1810 watts		19.3 19.2*	2350 watts		15.9 15.8*	1910 watts		18.6 18.4*

†Speedometer readings.
*Speed (km. per hr.) obtained from stop watch readings and distance measurement.

	East	West
Average battery output (watts)	2340	1850
Average speed by stop watch (km./hr.)	15.7	19.0

NOTE: Two independent speedometers were employed and read in each test; in the above table one set of speed values has been omitted. Calibration corrections have been applied to instrument readings.

losses added to the outputs, gave the total generator inputs supplied through the driving belts.

The losses in the two driving belts B_1 B_2, Fig. 8, were approximately determined by taking two successive light load tests, first with the regular heavy leather belts shown in Fig. 8, and next with special light cotton belts of negligible power loss, but of very limited transmitting capacity. The difference between the inputs, in these two tests, measured the power consumed in the leather belts; because the other losses in the two tests were the same.

The friction losses in the front wheels (about 70 watts total), were also measured by belting them to the rear wheels through light belts in special tests. No allowance was made for any possible increase in wheel-bearing friction under increased gravitational pressures; but since all the wheels had roller axle bearings, such extra friction losses were probably very small.

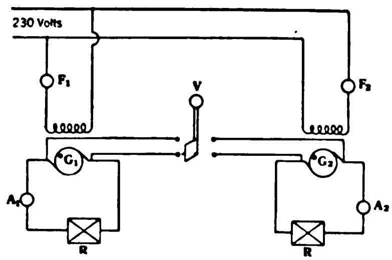

FIG. 9—DIAGRAM OF CONNECTIONS FOR DETERMINATION OF TEST TRUCK OVER-ALL EFFICIENCY BY MEANS OF LOAD GENERATORS G_1 AND G_2

Each generator was belted to one of the rear truck-wheels

The sum of the load-generator outputs, the armature losses, and belt losses, was taken as the car output at rear-wheel treads, at various measured inputs.

A detailed quantitative analysis of these various losses appears in the next section.

RESULTS OF TESTS

Although the primary object of this research has been a determination of tractive resistances to an electric truck, under the conditions previously defined; yet, incidentally the tests have furnished results of practical value of the overall efficiency from battery terminals to wheel treads of this type of electric car, under normal operating conditions.

Overall Efficiency of Driving Mechanism. A summary of typical data obtained in one of the laboratory tests is given in Table II. The first column gives the output in watts at the battery terminals, determined from the simultaneous readings of a calibrated voltmeter and ammeter, V, A, Fig. 6. Column II gives peripheral wheel speeds in km. per hr. and in miles

TABLE II.

DATA AND RESULTS FOR OVER-ALL EFFICIENCY OF TEST TRUCK

CONTROLLER ON POINT 4 FORWARD; BATTERY FULLY CHARGED.

I.	II.		III.	IV.	V.	VI.	VII.	VIII.	IX.
				Losses for generators					
Battery output	Peripheral rear wheel speed		Sum of generator outputs	Armature copper	Stray power	Belt losses	Sum of gen. outputs and losses	Equivalent truck output on road	Overall efficiency per cent
watts	km./hr.	miles/hr.	watts	watts	watts	watts	watts	watts	
1860	31.6	19.7	0	0	895	237	1132	1066	57.3
2390	25.7	16.0	872	4	645	161	1682	1616	67.6
2770	23.1	14.4	1289	11	632	130	2062	1996	72.0
3350	20.0	12.4	2001	36	529	98	2664	2598	78.5
3570	19.2	11.9	2230	50	499	90	2869	2803	78.5
3790	18.3	11.4	2420	65	471	86	3042	2976	78.5
3980	17.6	10.9	2560	80	447	77	3164	3098	77.8
4130	17.0	10.6	2656	96	427	72	3251	3185	77.2
4470	16.1	10.0	2920	132	399	65	3516	3450	77.1
4720	15.6	9.7	3090	167	377	59	3693	3627	76.8
4940	15.0	9.3	3270	204	361	56	3891	3825	77.5
5075	14.5	9.0	3317	236	341	53	3947	3881	76.5
5290	14.3	8.9	3274	262	322	50	3908	3842	72.7

per hr., derived from the voltage readings of magnetos M, m, Fig. 8. Column III gives the total generator output as determined by simultaneous readings of calibrated instruments V, A_1 and A_2, Fig. 9. Columns IV, V and VI itemize the following losses: (IV) armature copper losses (watts) in generators G_1 G_2, as obtained by resistance measurements of armatures, and from the observed armature currents (ammeters A_1 A_2, Fig. 9.); (V) stray power losses (watts) in generators G_1 G_2, as determined from special stray-power tests, already referred to; (VI) belt losses; *i.e.*, frictions in both driving belts B_1 and B_2, as determined by special belt-loss tests, already mentioned. Column VII gives the sum of the losses in columns III, IV, V and VI. Column VIII gives the equivalent output of truck on road, as obtained by subtracting from the watts tabulated in column VII, 66 watts for average front-wheel friction, the latter as determined by the special front-wheel friction-loss test already mentioned. The last column gives the over-all efficiency of the car for road runs, *i. e.*, the ratio of columns VIII and I.

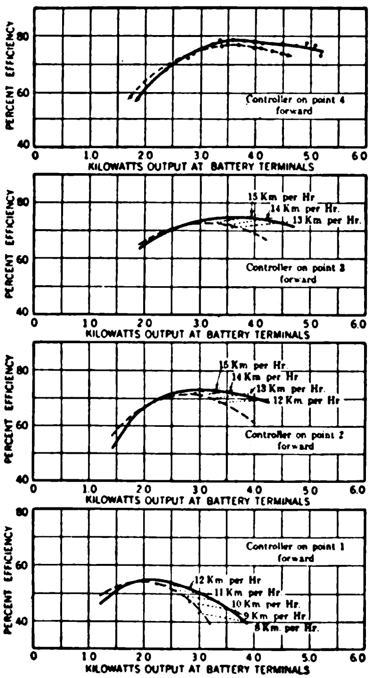

FIG. 10—CURVES OF OVER-ALL EFFICIENCY OF TEST TRUCK

With battery fully charged (full lines)—and with battery partially discharged (dash lines)—Dotted lines are drawn at constant rear-wheel peripheral speeds,as indicated—60 alkaline cells, type A6, were used.

Efficiency tests as elaborated in Table II were made at each controller position for forward speeds. In view of the relatively large voltage variation (see Fig. 7) of the truck battery, between full charge and partial or complete discharge, and at different current outputs, it was found necessary to perform efficiency-test runs; (1) at a fully charged battery and (2) at a partially discharged battery, (1) corresponding to high impressed voltage and (2) to a slightly lower impressed voltage. The results of the efficiency tests are shown in Fig. 10. It is seen that the condition of the battery has a considerable effect upon the re-

sults. Fig. 10 shows, besides efficiency curves at fully charged battery (full lines), and at partly discharged battery (dash lines), a number of constant speed lines (dotted). For example, the over-all road efficiency of the truck at 3500 watts battery output, controller on point 2, and at a truck speed of 13 km. per hr. (8.1 miles per hr.) is 71 per cent from Fig. 10. It was for convenience in the handling of the data that the truck speed was chosen as the third factor necessary for the determination of the truck efficiency, rather than the battery terminal voltage. It should also be pointed out that none of the efficiency curves in Fig. 10 are drawn at constant battery terminal voltage, and that they are, therefore, only approximately comparable to the manufacturers' motor efficiency curves reproduced in Fig. 5. Such an approximate comparison shows that the efficiency of transmission between motor and rear-wheel treads is in the neighborhood of 90 per cent for this truck under the conditions tested. This high value may be attributed to the fact that the driving mechanism involves but a single speed reduction, between motor and rear axle, by a worm and worm wheel (Fig. 4). The maximum values of over-all efficiency, including all mechanical and electrical losses beyond the battery terminals are seen from Fig. 10 to be as follow, when an approximately fully charged battery (60 cells, type A 6)is employed.

55 per cent, controller on point 1, forward at a battery output of 2000 watts.

73 per cent, controller on point 2, forward at a battery output of 3000 watts.

75 per cent, controller on point 3, forward at a battery output of 3500 watts.

78 per cent, controller on point 4, forward at a battery output of 3700 watts.

Tractive Resistance. The complete data and results for tractive resistance are shown, for a typical test run, in Table III. In columns I and II are tabulated the controller position and the direction of run, respectively, as previously defined. The speed (average of stopwatch readings divided into measured length of run for three consecutive tests) is given in column III. Column IV contains the average battery output in watts, already referred to (See Table I). Column V contains the number of meters of rise of elevation between start and finish. The average time of run (see Table I) is shown in column VI. The truck over-all efficiency, as taken from the efficiency curves (Fig. 10), is tabulated in column VII. Columns VIII, IX and X contain the follow-

TABLE III.

TEST DATA AND RESULTS FOR RUN NO. 19

Gross weight = 2140 kg. (4710 lb.)
Length of run = 274 m. (900 ft.)
Description of Road = Tar macadam.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
							Power losses (watts)						
Cont. pos.	Dir. of run	Speed $\frac{km.}{hr.}$	Batt. output watts	Incr. of elev. m.	Time of run sec.	Overall eff. of truck per cent	In truck	Against gravity	Due to change of kin. energy	Total	Tract. power watts	Tract. resist. $\frac{kg.}{met.ton.}$	Equiv. per cent grade
1	W	15.7	2340	+ 1.31	63.0	54.5	1063	436	−76	1423	917	10.0	1.0
2	W	18.3	2370	+ 1.31	53.9	70.0	712	510	− 9	1213	1157	10.8	1.08
3	W	19.6	2600	+ 1.31	50.4	71.0	755	546	20	1321	1279	11.2	1.12
4	W	21.8	2970	+ 1.31	45.2	75.0	743	608	80	1431	1539	12.1	1.21
1	E	19.0	1850	− 1.31	52.0	54.0	850	−529	48	369	1481	13.4	1.34
2	E	20.9	1920	− 1.31	47.4	65.5	662	−580	117	199	1721	14.2	1.42
3	E	22.4	2050	− 1.31	44.2	66.0	696	−621	118	193	1857	14.3	1.43
4	E	24.5	2500	− 1.31	40.2	69.5	763	−683	271	351	2149	15.0	1.50

TABLE IV.

TEST DATA AND RESULTS FOR LOSS OF POWER DUE TO CHANGE OF KINETIC ENERGY OF TEST TRUCK FOR RUN 19

Controller point	1		2		3		4	
Direction of run	West	East	West	East	West	East	West	East
v_2 average speed at finish $\frac{km.}{hr.}$	15.1	19.3	18.25	21.8	19.8	23.0	22.6	26.2
v_1 average speed at start $\frac{km.}{hr.}$	16.9	18.5	18.4	20.2	19.5	21.7	21.6	23.5
$v_2^2 - v_1^2$	− 58	30	− 6	67	12	58	44	134
Average time of run, sec.	63.0	52.0	53.9	47.4	50.4	44.2	45.2	40.2
Average power lost in accelerating truck, watts	− 76	48	− 9	117	20	118	80	271

ing power losses in watts: (VIII) in truck, as obtained from (IV) and (VII); (IX) against gravity; (X) due to change of kinetic energy of truck between start and finish (see table IV), all of which losses are supplied by the storage battery. In column XI are tabulated the sum of the entries of columns VIII, IX and X. The difference between (IV) and (XI) gives the total tractive power, as recorded in XII. Column XIII contains the tractive resistance in kg. per metric ton as derived from XII. The last column contains the equivalent percentage of grade, since 10 kg. per metric ton is just equivalent to 1 per cent grade.

The test data and results for loss of power, due to change of kinetic energy of the truck, for a typical road test are tabulated in Table IV. The results are negative for runs in which the velocity decreased. It is seen from the magnitude of these results, that they are by no means negligible. In practically all the road tests, this item was found to be of importance.

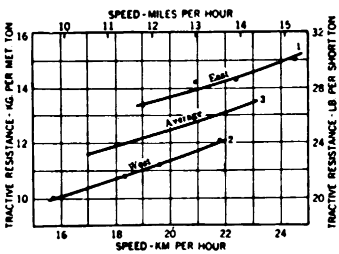

FIG. 11—CURVES OF LEVEL-ROAD TRACTIVE RESISTANCE FOR RUN 19

Pavement: tar macadam in good condition wet—wind east—curves 1 and 2 include the effects of the wind resistance—in curve 3 these effects are approximately eliminated, but not the still-air resistance.

In Fig. 11 are plotted the results for a typical test, in accordance with Table III. The ordinates of curve 3 represent the horizontal force per metric ton, and per short ton, which is required to overcome the road resistance, and still-air resistance, at constant speed on level road, with no wind blowing. Curves similar to those of Fig. 11 were plotted for each road test. A summary of the tests is represented by Figs. 12 to 18 inclusive.

Asphalt Roads, (Fig. 12.) The curves plotted in Fig. 12 apply to both sheet asphalt (*a*) and to bitulithic pavements (*b*), both defined as follow: (*a*) asphalt consisting of (1) a foundation of hydraulic cement or concrete, (2) a binder course of broken stone and asphaltic cement (dissolved asphalt), (3) a surface layer of asphaltic cement mixed with sand; (*b*) bitulithic pavement, which may be classified as a type of asphalt-macadam pavement, built on a concrete, stone-block or macadam foundation, consisting of a mixture of broken stone, sand and asphaltic cement, proportioned and mixed before being laid. This mixture, after having been laid hot, and rolled, is covered with a coat of hot asphaltic cement and fine stone chips.

The tests showed that there was no appreciable difference between the tractive resistances of sheet asphalt and bitulithic pavements as above defined when in good condition; so that both of these pavements are represented on one and the same diagram Fig. 12. The asphalt pavement, when in good condition, offers a low resistance to vehicular traffic, on account of its smoothness and hardness. Curve (1) is seen to be almost flat, and if the still-air resistance is eliminated by an approximate formula*, a straight horizontal line, (see curve 5), results for the road resistance alone. Curves 2 and 3 are steepened by the addition of impact and vibration losses. These extra losses are due to the impacts which the truck receives as it encounters local lumps and hollows in the worn pavement. The dash-line curve

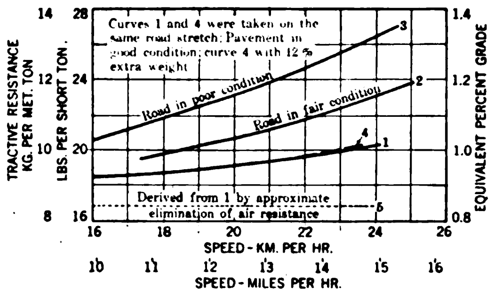

Fig. 12—Tractive Resistance for Asphalt Roads

Sheet asphalt and asphalt macadam and bitulithic.

was obtained when the total moving mass was increased 12 per cent, and is seen to be almost identical with curve 1.

Wood-Block Roads, (Fig. 13). The full-line curve of Fig. 13 applies to wood-block paving, which consists of rectangular

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$$*P = 0.0025 \frac{A.V^2}{W} \qquad \text{lb. per short ton}$$

air resistance, in which formula A is the cross-section of the car in sq. ft., V the speed of the car in miles per hr., and W the total mass in motion (in short tons); see American Handbook for Electrical Engineers, 1914, Wiley, New York, p. 1166. In metric units, the above equation takes the form

$$P = 0.0047 \frac{av^2}{w} \qquad \text{kg. per metric ton}$$

if a is expressed in sq. m., v in km. per hr. and w in metric tons. The area offered to the air by the test truck was approximately 14 sq. ft. (1.3 sq. m.) and the moving mass was 2.36 short tons (2.14 met. tons), except when otherwise noted.

creosoted hard-pine blocks, approximately 4 in. (10 cm.) deep, 3.5 in. (9 cm.) wide and 8 in. (20 cm.) long, placed, with the fiber vertical, and the long dimension crosswise to the street, upon a foundation of concrete with a thin layer of sand interposed between concrete and wood blocks. The curve is nearly horizontal because of the smoothness of the pavement.

Brick-Block Roads, (Fig. 13). The brick-block roads upon which tests were made, consisted of rectangular vitrified paving brick, approximately 4 in. (10 cm.) deep, 3.5 in. (9 cm.) wide, and 8.5 in. (21.5 cm.) long, laid with the length perpendicular to the curb, upon a foundation of concrete and a cushion layer of sand. The results for brick roads show nearly as low a resistance as those for the wood block, but the curve for the former is steeper, particularly for the case of a worn surface, again

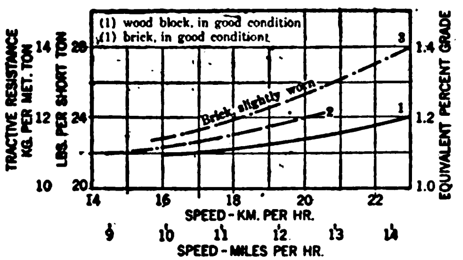

FIG. 13—TRACTIVE RESISTANCE FOR WOOD-BLOCK AND BRICK-BLOCK ROADS

probably because of the impact and vibration losses on the rougher pavement.

Granite-Block Roads, (Fig. 14). The foundation for these roads is either a bed of sand, or a layer of concrete, with a sand cushion to separate the blocks from the concrete. Average dimensions for the rectangular blocks are about 4 in. (10 cm.) wide, 11 in. (28 cm.) long and 8 in. (20 cm. deep). The joints are filled either with small pebbles and sand, or with hydraulic-cement grout. The former filler is subject to being partially washed out by precipitation, and removed by the street sweeper, and thus allows the edges of the blocks to be exposed to wear, which renders the pavement far less smooth than one with cement-filled joints. The full-line curves 1 and 2 in Fig. 14, which apply to granite-block roads with cement-filled joints, show a greater upward slope than those for the smoother brick-block, wood-block, and asphalt roads, already mentioned; while the

granite-block pavements constructed with the less durable filler are seen to offer a still more rapidly increasing resistance at increasing velocities, because of the greater losses of kinetic energy due to road impact.

Macadam Roads, (Fig. 15 and 16). This type of road has a pavement consisting of several layers of broken stone, (trap rock, granite, lime stone, slate, etc.) ranging in size from about 3 in. (7.6 cm.) to about 0.5 in. (1.3 cm.) in largest dimension. The fragments of stone are held together by a binding material of which there are two general types: (1) clay, loam, sand, or finest screenings (stone dust from stone crusher), distributed

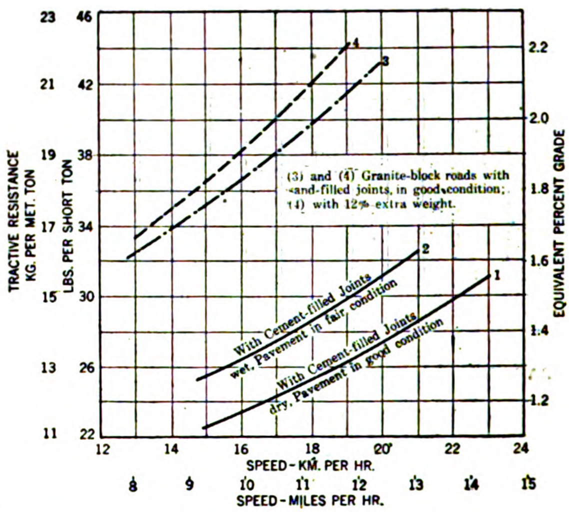

FIG. 14—TRACTIVE RESISTANCE FOR GRANITE-BLOCK ROADS

over each layer of broken stone, water being sprinkled over the surface; and (2) tar, either mixed with the broken stone before it is laid, or distributed over the broken stone, after the latter has been spread and rolled; type (1) is known as a water-bound macadam, and type (2) as tar-macadam.

Fig. 15 shows the results obtained for water-bound macadam roads, the dot-dash curves apply to the oiled pavements, full-line curves are for unoiled roads. A dusty road (curve 2), is seen to have a greater resistance than a similar one with a hard surface without dust (curve 1); while a badly worn road with holes (curve 3), shows a far higher resistance than 1 and 2, and a much more rapid rise with increasing speed, due to impact

losses. Curve 4 for an oiled macadam road, though in fair condition, shows a higher resistance than a similar road unoiled. Heavy oiling increases the resistance without increasing the slope of the curve, as indicated by curve 5; this effect is probably caused by the softening of the surface and the resultant loss of power due to the depression of the surface material by the wheel tires. The combined effects of wear and oil are seen in curve 6. Curve 7, if compared with curve 5, (the two curves applying to the same road, but to different days and different total weights of moving vehicle), shows a slight increase of

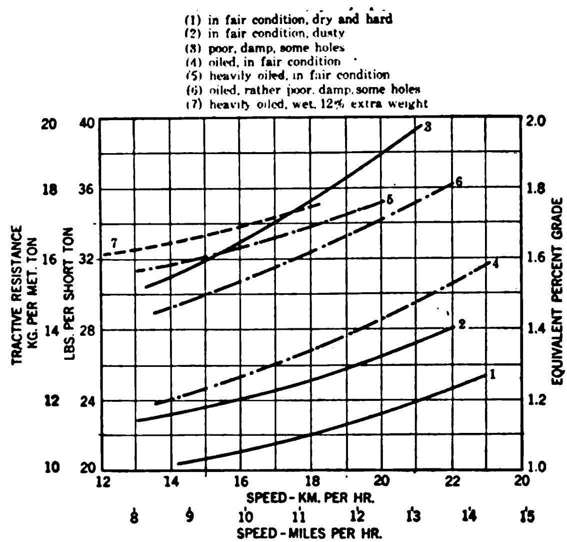

FIG. 15—TRACTIVE RESISTANCE FOR MACADAM ROADS

resistance due probably to both decreased road resilience and increased weight.

The results for tar-macadam roads, (Fig.16) are similar to those for water-bonded macadam; *i.e.*, the effects of surface deterioration are definitely seen by comparison of curves 1, 2, 3 and 4. Curve 5 is of interest in again demonstrating that the resistance of a soft surface of low resilience is greater than that of a similar but hard road by an approximately constant amount, (see curves 5 and 1). The dash-line, curve 6, (12 per cent extra weight), is seen to follow very closely curve 2, (the two curves include data obtained on the same road under similar conditions, but with different total weights.)

Cinder and Gravel Roads (Fig. 17.) Curve 1 in Fig. 17 applies to a road with a gravel surface, in fair condition, but slightly dusty. A cinder road with a dry and hard surface in fair condition, is seen to have a slightly lower resistance, probably because of its greater resilience.

Summary for All Classes of Urban Roads Tested. Typical results for all classes of urban roads tested are summarized graphically in Fig. 18, and numerically in Table V. It appears from these summaries, and from the foregoing discussions, that

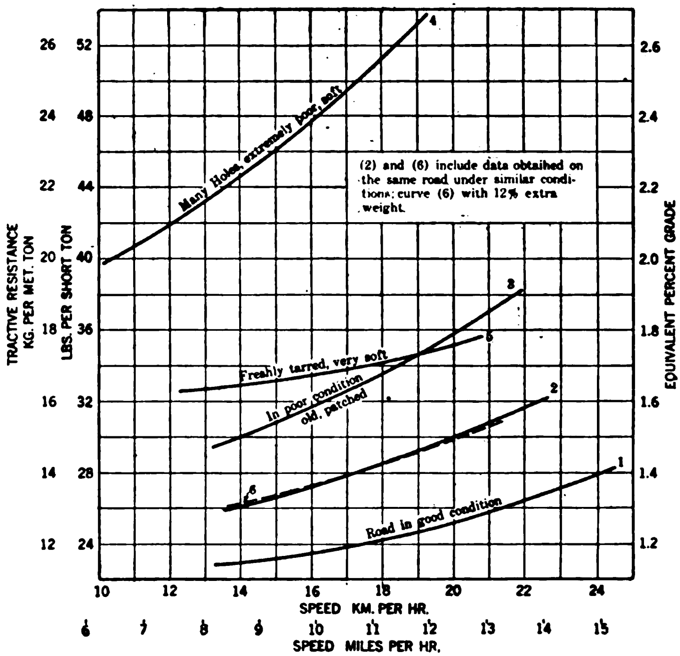

Fig. 16—Tractive Resistance for Tar-Macadam Roads

there are three principal elements which determine the tractive-resistance-speed curve for unit weight of a given vehicle, within the range of conditions covered by this test:

(1) A constant resistance, see curve 1, Fig. 19*, the magnitude A of which depends on the lack of resilience of the road surface and wheel tire material, *i.e.*, on the energy losses due to displacement of tire material and road-surface material. This constant element A would be encountered upon a smooth level road

*The quantitative data of Fig. 19 refer to the asphalt roads of Fig. 12.

of the particular type considered, in the absence of impact, air, and wind-resistances.

(2) An increasing resistance with increasing speed, due to

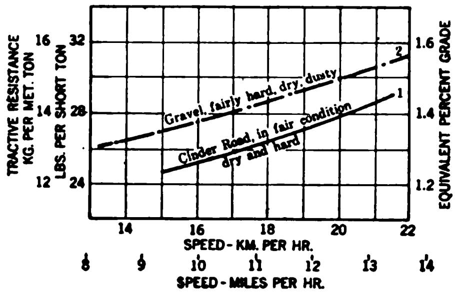

FIG. 17—TRACTIVE RESISTANCE FOR GRAVEL AND FOR CINDER ROADS

impact losses (curve 2), which results from lack of smoothness of road surface; losses of this nature are usually known to vary approximately as the second power of the velocity at impact; and

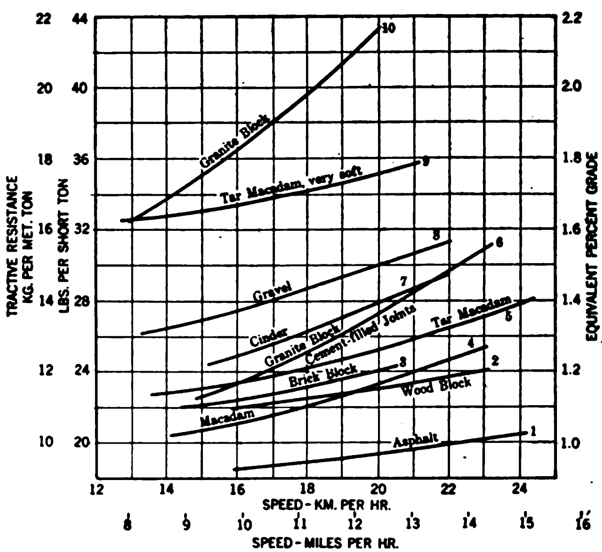

FIG. 18—SUMMARY OF TRACTIVE RESISTANCE TESTS

(3) An increasing resistance with increased speed, due to air pressure against the front of the vehicle, curve 3, which resistance is known to depend, roughly, on the second power of the speed (see above under "Asphalt Roads"). The sum of the three

TABLE V.

SUMMARY OF TRACTIVE RESISTANCES OF DIFFERENT URBAN ROADS AT DIFFERENT SPEEDS

All tractive resistances are expressed in equivalent per cent grade.

Road		Equivalent per cent grade		Per cent increase in tractive resistance from 16 to 20 km. per hr.	Comparative tractive resistance factors referred to asphalt roads	
Type	Condition	at 16 km./hr. (10 miles per hour)	at 20 km./hr. (12.4 miles per hour)		at 16 km./hr.	at 20 km./hr.
Asphalt	good	0.93	0.97	4	1.0	1.0
Asphalt	poor	1.03	1.16	11	1.11	1.20
Wood block	good	1.10	1.15	5	1.18	1.18
Brick block	good	1.12	1.21	8	1.20	1.25
Brick block	slightly worn	1.14	1.27	11	1.23	1.31
Granite block	good	1.83	2.16	18	1.97	2.23
Granite block with cement joints	good	1.16	1.37	18	1.25	1.41
Macadam, water bonded	dry and hard	1.06	1.17	10	1.14	1.20
Macadam, water bonded	fair, heavily oiled	1.63	1.76	8	1.75	1.82
Macadam, water bonded	poor, damp some holes	1.65	1.89	15	1.78	1.95
Tar macadam	good	1.17	1.27	9	1.26	1.31
Tar macadam	very soft	1.67	1.76	5	1.80	1.81
Tar macadam	many holes, extremely poor, soft	2.38	2.75	16	2.55	2.85
Cinder	fair, hard	1.25	1.39	11	1.35	1.43
Gravel	fair, dusty	1.37	1.50	9	1.47	1.55

curves for items 1, 2, and 3, for the case of asphalt roads in Fig. 12, results in curve 4. The constant resistance (1) may be briefly called the *displacement resistance*, item 2 the *impact resistance*, and item 3 the *air resistance*. The displacement resistance is low for hard pavements (curve 1, Fig. 12) and high for soft pavements (of low resilience), as is illustrated by curve 5, Fig. 16; The impact resistance is very marked in granite-block roads, as already mentioned, (Fig. 14). The air resistance, at any definite velocity, is the same for all curves; because the

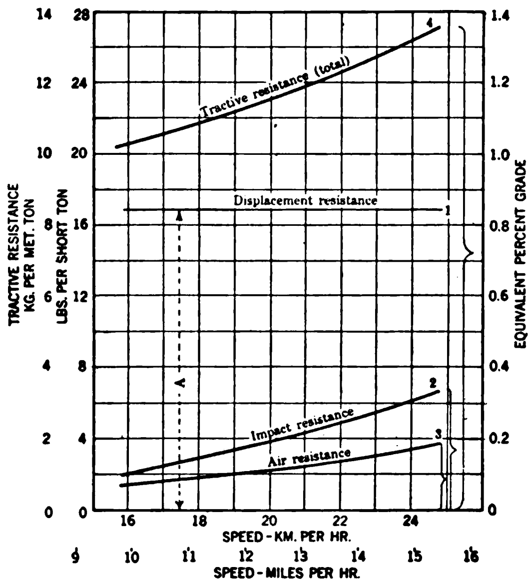

FIG. 19—APPROXIMATE ANALYSIS OF TYPICAL TRACTIVE RESISTANCE INTO ITS ELEMENTS, FOR ASPHALT ROAD IN POOR CONDITION (CURVE 3, FIG. 12)

air-resisting parts of the truck were left unchanged throughout the tests. For the particular type of road represented by Fig. 19 (asphalt road in poor condition, see curve 3, Fig. 12), at a speed of 20 km. per hour (12.4 miles per hr.) the displacement resistance is 0.84 per cent, the air resistance is 0.11 per cent, the impact resistance 0.20 per cent and the total 1.15 per cent equivalent grade.

The displacement resistance of a road manifestly varies, not only with the type and surface quality of the road, but also with the type, dimensions and quality of the tires on the wheels

of the vehicle. In the tests here reported, the same tires were used throughout, and they remained in substantially the same condition.

The impact resistance of a road manifestly depends not only on the type and surface quality of the road, and the sizes of its irregularities; but also on the type, dimensions and quality of the wheel tires, the weight of the truck, and the quality of its springs.

The air resistance per unit weight of truck manifestly depends upon the weight, dimensions and shape of the vehicle, as well as on the speed of the vehicle relatively to the surrounding air.

The wind resistance per unit weight of truck manifestly depends upon the weight, dimensions and shape of the vehicle, as well as on the direction and velocity of the wind and the velocity of the vehicle. It is assumed that at low wind and vehicle-speeds, like those here considered, only that component of the wind which is in the direction of the vehicle's path needs to be taken into account, and that the mean of the wind resistances in opposite directions, along the road, is zero.

The following studies are suggested for future experimenters along the line of this investigation:

(1) Researches on vehicle tractive resistances on country roads.

(2) Tractive resistances to vehicles with different wheel tires.

(3) Tractive resistances of urban roads at low speeds from 0 to 10 miles per hour (16 km. per hr.)

(4) Tractive resistances at speeds higher than 15 miles per hour, (24 km. per hr.)

(5) Tractive resistances for heavy-duty trucks.

In conclusion, the authors wish to express their indebtedness to Mr. Thomas A. Edison and the Gould Storage Battery Co., who contributed the funds for carrying out the work; to the General Vehicle Co. for the loan of the truck used in the tests; and to the Edison Electric Illuminating Co. of Boston for their helpful assistance in several stages of this research. Further acknowledgment is due to Messrs. A. C. Brown (S. B., M. I. T. 1914) and F. B. Barns, (S. B., M. I. T. 1915), who took most of the observations during road and laboratory tests, and to Messrs. D. J. McGrath (S.B., M. I. T. 1912) and L. H. Webber (S. B., M. I. T. 1914) who rendered assistance in the preparation of the results.

Summary of Conclusions

The following conclusions are indicated from the preceding results: as confined to urban roads, with a solid rubber tired motor truck between the speed limits of from 13 to 25 kilometers per hour, (8 to 15.5 miles per hour.)

(1) The over-all efficiency of the test-truck mechanism, as described in this report, between battery terminals and rear-wheel treads, reached a maximum value of about 78 per cent, under the most favorable conditions.

(2) The mechanical efficiency of transmission from motor shaft to rear-wheel treads, for the truck tested, shaft-driven through a single-reduction worm gear, was found as high as 90 per cent.

(3) Tractive resistances are most conveniently expressed as an equivalent percentage grade; *i.e.*, a level road of definite tractive resistance may be regarded as a road of zero tractive resistance, but rising uniformly x units in 100 units of road length, or having an equivalent grade of x per cent.

(4) Under the conditions of these tests, the tractive resistance on level roads, in the absence of wind, is composed of (a) displacement resistance, (b) impact resistance, and (c) air resistance.

(5) The displacement resistance varied from 0.85 per cent equivalent grade, for a hard smooth asphalt or bituminous concrete to 1.6 per cent for a very soft tar-macadam road, and was practically constant, for all speeds considered, on any given road.

(6) The impact resistance increases with the velocity, with the total weight of vehicle, and with increasing road-surface roughness. In these tests, the impact resistance of good asphalt or bitulithic or other smooth pavement, was practically negligible, and reached its highest values on granite-block roads with sand filled joints, and on badly worn macadam pavements. The rate of increase of impact resistance with speed was most marked on the roughest roads.

(7) At the vehicle speed of 20 km. (12.4 miles) per hour, the air resistance for the vehicle tested, assumed to be dependent only on the speed, was roughly 0.11 per cent equivalent grade; *i. e.*, from 4 per cent of the highest, to 12.5 per cent of the lowest, total tractive resistance.

(8) The following urban pavements are enumerated in the order of their desirability for vehicle operation from the point

of view of tractive resistance at 20 km. (12.4 miles) per hr., as found in this investigation. (1) asphalt, (2) wood block, (3) hard smooth macadam, (4) brick block, (5) granite block with cement-filled joints, (6) cinder, (7) gravel, (8) granite block with sand-filled joints.

(9) The equivalent grade at 20 km. (12.4 miles) per hr. of a badly worn city macadam road, was found to be nearly three times as great as that of the best asphalt road tested. This means, at this speed, a consumption of energy at wheel treads, of nearly three times as much on level poor macadam roads as on good level asphalt roads.

(10) Increasing the gross weight of the vehicle by 12 per cent, through load, was found to have no effect on tractive resistance within the observed speed limits for smooth roads in good condition; but on rough roads, a distinct increase in tractive resistance with this extra weight was observed.

(11) The presence of a layer of dust, say one cm. thick, on a fair macadam road, was found to increase the equivalent grade of tractive resistance, at all tested speeds, by about 0.15 per cent.

(12) A freshly tarred and therefore very soft tar-macadam road was found to have an increased tractive resistance equivalent, at substantially all tested speeds, of about 0.5 per cent. The tires in this case sank about 0.8 inch (2 cm.) into the road bed, the gross car weight being 2140 kg. (4710 lb.)

(13) The total range of tractive resistance equivalent grade covered in the tests, was from 0.93 per cent on the best asphalt road, at lowest speed, to 2.7 per cent on the worst macadam road, at nearly the highest speed.

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[1]These experiments cover tractive resistances, principally at low speeds of about 3 miles per hr. (4.8 km. per hr.), for gun carriages, freight cars, artillery wagons, freight wagons, stage coaches, carriages, and wagons, (the latter three with springs), on miscellaneous surfaces.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

REPORT OF THE BOARD OF DIRECTORS FOR THE FISCAL YEAR ENDING APRIL 30, 1916

The Board of Directors of the American Institute of Electrical Engineers presents herewith to the membership its Thirty-Second Annual Report, for the fiscal year ending April 30, 1916. A General Balance Sheet showing the financial condition of the Institute on April 30, 1916, together with other financial statements, is included herein.

The Board has endeavored, as far as possible, to keep the membership informed of its proceedings by publishing monthly in the Institute PROCEEDINGS a resumé of the business transacted at each meeting. These notices, however, are necessarily incomplete, as many important matters are considered which cannot be disposed of at one meeting and which must be held over for future consideration and action. Eventually such matters are dealt with in subsequent issues.

Directors' Meetings.—During the year the Board of Directors held 10 regular meetings, one adjourned meeting, and one special meeting. The adjourned meeting was held on December 11, 1915, for the purpose of considering the report of the Constitutional Revision Committee. The special meeting was held on January 21, 1916, for the purpose of acting upon an invitation from President Wilson to President Carty to nominate from the Institute's membership, candidates for appointment by the Secretary of the Navy upon the Organization for Industrial Preparedness, referred to elsewhere in this report.

Eleven of these meetings were held in New York, and one in Deer Park, Md., during the Annual Convention.

Annual Convention.—The Thirty-Second Annual Convention was held in Deer Park, Maryland, June 29-July 2, 1915. The total attendance was 202, which included 43 ladies. Although the attendance was small, due possibly to the location being somewhat remote from the larger membership centers, the convention was very successful from a technical and social standpoint. Thirty-one papers were presented at the seven technical sessions.

Panama-Pacific Convention.—The Panama-Pacific Convention was held in San Francisco September 16-18, 1915. It was arranged chiefly to provide an Institute meeting in San Francisco for Pacific coast members during the Panama-Pacific Exposition in place of the International Electrical Congress, which had been scheduled to be held on the same dates, but which had been postponed. The convention was unusually successful. Three hundred and fifty-five members registered, of which a considerable number were eastern members visiting the Exposition and attending the International Engineering Congress. Twenty-six papers were presented on a variety of engineering subjects.

Midwinter Convention, New York.—The Fourth Midwinter Convention was held in New York on February 8 and 9, 1916. The total registered attendance was 671, of which number 380 were members. The 291 guests included 175 ladies. Eleven papers were presented and four technical sessions were held. A subscription dinner-dance was held at the Hotel Astor on the evening of February 8, which was attended by 425

members and guests. The proceeds from the sale of tickets to this function covered all of the expenses and provided a surplus which will be available towards defraying the expenses of future midwinter social functions.

Philadelphia Meeting.—An Institute meeting was held in Philadelphia, Pa., on October 11, 1915, under the auspices of the Philadelphia Section. Three papers were presented and the total attendance was 200. This is the third annual meeting of this kind to be held in Philadelphia at the opening of the active season.

St. Louis Meeting.—On October 19 and 20, 1915, Institute members in the middle west were given an opportunity to attend a two-day Institute meeting which was held in St. Louis, Mo., under the auspices of the St. Louis Section, on the occasion of the 100th meeting of that Section. Eleven papers were presented, and the total attendance was 201. Members of the Associated Engineering Societies of St. Louis, with which the Section is affiliated, participated in this meeting.

Water Power Meeting, Washington, D. C.—This meeting was held in Washington on April 26, 1916, under the auspices of the Washington Section and the Committee on Development of Water Power. Five very carefully prepared papers were presented on the general subject of the relation of water power to the industrial advancement of the country. Two-hundred and fifty members and invited guests attended the meeting.

National Meeting, May 16, 1916.—An event unique in the history of the Institute and one which is attracting widespread interest will take place on May 16, 1916. This is a National Meeting which will be held simultaneously through the medium of the long distance telephone in six different cities; namely, San Francisco, Chicago, Atlanta, Philadelphia, New York and Boston. The purpose of the meeting is to commemorate the achievements of Institute members in the fields of communication, transportation, lighting and power. Incidentally it is being held on the date of the Annual Meeting of the Institute, and although the business coming before the Annual Meeting will be transacted in the afternoon at the business meeting, it is planned to reserve a part of it for the National Meeting in the evening.

Other Meetings.—In addition to these special meetings, held in various parts of the country for the benefit of the membership at large, eight regular monthly meetings were held in New York, with an average attendance of 300.

The Sections and Branches have also continued active and have held a large number of regular monthly meetings as shown by the tabulated statement in the report of the Sections Committee.

President.—President Carty has presided at all meetings of the Institute held during the year, with the exception of the meeting in St. Louis, and also at all meetings of the Board of Directors. During the year he has attended the following meetings: Detroit, September 9, 1915, Joint Session of A. I. E. E. at Convention of Association of Iron and Steel Electrical Engineers: Panama-Pacific Convention, San Francisco, September 16-18, 1915; Institute Meeting, Philadelphia, October 11, 1915; Schenectady Section, October 12, 1915; Boston Section, October 13, 1915; Pittsburgh Section, December 4, 1915; Ithaca Section, March 25, 1916: Water Power Meeting, Washington, April 26, 1916.

International Engineering Congress.—The International Engineering Congress has already received such wide publicity through its Committee of Management that no extended reference to it is necessary in this report. The Institute was one of the five national engineering societies which planned the Congress and which was interested in its success. It was held in San Francisco on the dates scheduled, September 20-25, 1915, and was eminently successful in every way.

The total registered attendance at the Congress was 851, of which number 71 were from 20 foreign countries. Fifty-two technical sessions were held, and over 200 papers were presented on a wide range of engineering subjects. In addition to the registered attendance over 600 cards of admission were issued so that the attendance at the various sessions was well over 1,500. The Committee of Management is still acting, principally with the publication and distribution of the volumes of the transactions, which it is estimated will be in the neighborhood of 10,000 to 12,000. A full report will be submitted by the committee to the participating societies in the near future.

National Preparedness.—The Institute has taken an active part in a number of the movements which have been organized recently in the interest of adequate national preparedness. Chief among these are the National Engineer Reserve, the Naval Consulting Board, and the Organization for Industrial Preparedness.

National Engineer Reserve.—The suggestion for the organization of a National Engineer Reserve was first made early in 1915, and shortly thereafter a joint committee was formed of representatives of the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the American Institute of Electrical Engineers, and the American Institute of Consulting Engineers, to cooperate with the war department in the organization of such a reserve. The members of this committee being widely separated geographically, making full attendance at meetings difficult and impracticable a smaller working committee was formed consisting of the five chairman of the individual committees of each society constituting the joint committee. This arrangement greatly facilitated the work. The committee has held conferences with Major General Leonard Wood, officers of the General Staff of the U. S. Army and of the War College, and with the chairmen of the House and Senate legislative committees on military affairs. The result of this work is that several of the military measures before Congress embody provisions for an Officers Reserve Corps under which the engineers of the country may take service. The committee is now waiting for the Navy Department to formulate its plan for an increase of the naval forces, and as soon as a decision has been reached by that Department, the committee will take up the question of an engineer reserve for the Navy similar to that contemplated for the Army.

U. S. Naval Consulting Board.—On July 19, 1915, the Institute was invited by the Hon. Josephus Daniels, Secretary of the U. S. Navy Department, to select two members for appointment by Secretary Daniels upon a proposed advisory committee to be presided over by Mr. Thomas A. Edison and to be composed of men recognized throughout the country for their inventive genius and engineering achievements, to assist the Navy Department, both instructively and critically, in the development of such new

ideas for naval advance as might be presented and found worthy of consideration. The underlying idea was to make available the latent inventive and engineering genius of our country to improve the navy, and to bring the officers of the service into more intimate contact with the industrial resources of the country. Similar invitations were extended to ten other scientific and engineering organizations. The two members officially selected for this service by the Institute were Mr. Frank Julian Sprague, of New York, and Mr. Benjamin G. Lamme, of Pittsburgh, Pa., both of whom were appointed by Secretary Daniels as members of the Naval Consulting Board. The excellent work of the Board has already received so much attention from the public press that no further statement regarding it is necessary in this report. Recently its usefulness has been greatly enlarged by the organization of representatives from each state in the Union to assist in the work of collecting data regarding the manufacturing resources of the country.

Organization for Industrial Preparedness.—This movement was inaugurated as the result of the valuable service rendered by the Naval Consulting Board. Its purpose, as expressed in President Wilson's letter to President Carty inviting the Institute to nominate representatives, is to assist the Naval Consulting Board in the work of collecting data for use in organizing the manufacturing resources of the country for the public service in time of emergency. The Institute was invited to nominate, for the approval of the Secretary of the Navy, a representative from its membership from each state in the Union to act in conjunction with representatives of the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers and the American Chemical Society. At the call of President Carty the Board of Directors of the Institute held a special meeting on January 21, 1916, to act upon this invitation, and at this meeting President Carty was empowered to select the nominees on behalf of the Institute. A list of these nominees was subsequently submitted to the Secretary of the Navy and the appointments were made. The state representatives are officially known as the *State Directors of the Organization for Industrial Preparedness, and Associate Members of the Naval Consulting Board of the United States*, and it will be the duty of these directors to make a canvass of the industrial establishments in their respective States and have them fill out a confidential form giving in detail data regarding their manufacturing and producing resources. On April 20, 1916, President Carty issued a letter to all Institute members in the United States appealing to them to assist in the work.

Representatives.—In addition to its regular representation upon the various joint committees and other local and national bodies with which it has been affiliated in past years, the Institute has also appointed special representatives on numerous occasions during the year in connection with matters of interest to the Institute and to the engineering profession, especially in civic affairs and matters pertaining to legislation affecting the profession.

Committees.—There has been no change in the number and character of the standing, technical and special committees, but a committee has been investigating the fields of the respective technical committees, and it is probable that there will be some additions next year. With one or

two exceptions all of the committees have been more or less active. Abstracts of the reports of the chairmen of many of the Institute committees to the Board of Directors are included herein as follows:

Sections Committee.—The Sections Committee is able to report a gratifying increase in activity and interest on the part of the Sections and Branches during the year.

Although the number of meetings has not greatly increased, the attendance has been considerably larger, notwithstanding the fact that two Sections have necessarily been inactive during the present year; namely, Mexico and Toronto. The Toronto Section is inactive only temporarily.

Two new Sections were organized during the year; one at Denver, Colo., on May 18, 1915, and the other at Kansas City, Mo., on April 14, 1916. The Denver Section has made an excellent start and is doing good work. The Kansas City section was just organized a month ago and has therefore not yet had an opportunity to become active. The officers, however, are enthusiastic and the Section will doubtless be of great usefulness to the membership.

New Branches were organized at the Carnegie Institute of Technology, Clarkson College of Technology, and the Brooklyn Polytechnic Institute.

On April 14, 1916, the Board of Directors, acting upon the recommendation of the Sections Committee, authorized a conference of Branch delegates at the Annual Convention, similar to the conference of Section delegates which of late years has become such a prominent feature of the annual conventions. It was considered inexpedient, however, to recommend that the transportation expenses of the Branch delegates be paid from the Institute treasury.

In accordance with Section 60 A of the Institute by-laws, which was adopted upon recommendation of the committee, the Chairman is receiving suggestions of questions for discussion at the coming conference of Section delegates at the Cleveland Convention.

A tabulated table showing the activity of the Sections and Branches during the past five years follows:

	For Fiscal Year Ending				
	May 1 1912	May 1 1913	May 1 1914	May 1 1915	May 1 1916
Sections					
Number of Sections	28	29	30	31	32
Number of Section meetings held	231	244	233	246	251
Total Attendance	19,800	22,825	22,626	23,507	28,553
Branches					
Number of Branches	42	47	47	52	54
Number of Branch meetings held	281	357	306	328	360
Attendance	10,255	11,808	11,617	12,712	15,166

Meetings and Papers Committee.—The Meetings and Papers Committee has held regular monthly meetings throughout its term of office, at which meetings the disposition of all manuscripts submitted has been attended to and the regular Institute meetings and conventions decided upon. In addition to the monthly meetings in New York, meetings have been arranged for by this committee in St. Louis, Philadelphia and Washington. The Panama-Pacific Convention, the Midwinter Convention, the Annual Convention, Cleveland, and the Pacific Coast Convention at Seattle, have also been arranged for by this committee. Following its practise in previous years all manuscripts which have been submitted have first been passed upon by one of the special technical committees before being finally acted upon by the main committee.

Standards Committee.—The 1915 edition of the Standardization Rules, representing the work of the Standards Committee of 1914-1915, was presented to and approved by the Board of Directors at the Deer Park Convention meeting, July 1, 1915. The revision was not radical, but rather a completion and clarification of the radical revision of December 1, 1914.

The present committee has held monthly meetings for the consideration of amendments and additions. The work has been largely carried on through the medium of 20 sub-committees charged with various parts of the field, whose reports have been reviewed by the whole committee. No final action will be taken on the proposed amendments until the May meeting, which will probably last for several days.

The changes to be considered at the May meeting are for the most part not radical, although they constitute distinct improvements. These will be presented to the Board of Directors at the Cleveland Convention in June, and if approved will be incorporated in the 1916 edition which will become effective on August 1.

In order to insure greater continuity of policy and method in the work of the Standards Committee from year to year the committee will present to the Board of Directors for its approval a set of by-laws with the recommendation that any future changes thereto can be made only with the sanction of the Board.

During the year a number of additions have been made to the list of cooperating societies, which includes several foreign societies.

Code Committee.—The Code Committee has continued to represent the Institute on the Electrical Committee of the National Fire Protection Association. Only one meeting was held, in Boston, and nothing transpired at this meeting of sufficient importance to merit special mention.

A sub-committee of the Code Committee spent much time cooperating with the U. S. Bureau of Standards during the year, working on the National Safety Code which the Bureau is formulating and which it expects to issue sometime in the near future. This was a continuation of the kind of work carried on last year, and represents the real activity of the Code Committee for the year.

Library Committee.—The united libraries of the founder societies and the United Engineering Society are now controlled and administered as one joint library by the Library Board of the United Engineering Society

under an agreement which took effect on January 1, 1915, and in accordance with the by-laws of that society. The first annual report of the Library Board, for the year 1915, was issued and published in pamphlet form in January 1916. A synopsis of the report appeared in the Institute PROCEEDINGS for February 1916. It includes many interesting statistics of the accessions to the library, its utilization, its finances, and a list of the donors of books and pamphlets.

Railway Committee.—The Railway Committee this year has cooperated with the Standards Committee in respect to the revision of Rule No. 418 of the Standardization Rules, and has made suggestions regarding the rule for incorporation in the final edition of the Rules. Some consideration has been given to a more standard terminology for electric railway devices and the standardization of voltages for railroad purposes.

Transmission Committee.—The Transmission Committee has this year continued its practise of securing a consensus of opinion of the best informed engineers and operating men on some selected subject or subjects and either reproducing or digesting the material for the benefit of the membership. This year the committee will make reports at the Annual Convention on experiences in the effect of altitude in the operating temperature of electrical apparatus, and in the use of the grounded neutral in high tension systems.

Electric Lighting Committee.—The Electric Lighting Committee has held several meetings during the year at which the principal subject of discussion was the arrangement of circuits for street lighting purposes. A paper on this subject will be presented at the Annual Convention.

Industrial Power Committee.—As in previous years, the Industrial Power Committee cooperated with the Sections and Branches in arranging meetings on the subject of industrial power. The Cleveland Section appointed a local industrial power committee and later a considerable number of Sections and Branches followed its example. Each Section and Branch was requested to hold at least one meeting during the year on the subject of industrial power, and the local committees were of great assistance in arranging for these meetings. The Industrial Power Committee was also able to obtain for the use of the Sections and Branches a number of lantern slide lectures. The committee has been assigned one session of the Annual Convention. Four meetings were held during the year.

Electrochemical Committee.—The Electrochemical Committee has confined its work to efforts to obtain suitable papers on electrochemical subjects which the committee considered might be of general interest to the membership. The committee arranged for the joint meeting with the New York Section of the American Electrochemical Society held in New York on March 10, 1916.

Electrophysics Committee.—The work of the Electrophysics Committee has been directed chiefly to obtaining and reviewing, for the Meetings and Papers Committee, papers on subjects relating to the physical theory underlying the application of electricity to electrical engineering. Six papers have thus far been obtained and two others promised. Of the six, three have already been presented, one will be presented at the Annual Convention, and two will be offered for future meetings.

Iron and Steel Industry Committee.—This committee has arranged for a joint session between the A.I.E.E. and the Association of Iron and Steel Electrical Engineers, for Wednesday, September 20, 1916, during the annual convention of the Association to be held in Chicago, September 18-22, 1916.

Committee on Use of Electricity in Mines.—A session of the Panama-Pacific Convention held in San Francisco in September 1915 was devoted to mining work and a number of papers were presented dealing particularly with metal mine problems. Some work was also done by the committee in conjunction with the U. S. Bureau of Mines regarding rules for electrical installation in mines, but owing to business conditions it has not been possible to get the members of the committee together for a thorough discussion of the subject.

Committee on Use of Electricity in Marine Work.—The work of this committee has been directed, first, to obtaining papers dealing with electrical installations on shipboard, and, second, to continuing the work carried on during the previous two years in securing standard rules for various types of marine installations. A paper on this subject was presented at the Panama-Pacific Convention, and several papers are in view dealing with auxiliary power plants on shipboard for lighting, and for power for radio telegraph sets in cases of emergencies.

A sub-committee of this committee is now at work in conjunction with Lloyds and the American Bureau of Shipping in an endeavor to bring up to date and standardize the rules of the various building and insurance societies.

Protective Apparatus Committee.—The work of the Protective Apparatus Committee during the year might be divided into five categories, as follows: 1. An endeavor to standardize lightning arresters and similar protective devices. 2. Consideration and discussion of the factors involved in attempting to standardize the rating of oil switches. 3. An analysis of the protective problems connected with relays, split conductor cables, and like protective means. 4. Collection of data on partially solved problems relating to protective devices and continuity of service in the transmission of electrical energy. 5. Presentation of data in the form of papers; four dealing with operating experiences with protective devices, three on pressing problems relating to line insulators, and one on the theory of parallel grounded wires.

Committee on Records and Appraisals of Properties.—The geographical distribution of the committee has made it necessary to carry on its work through the medium of correspondence. One of the results of the committee's work was the presentation of several very important papers on various phases of appraisal work at the Panama-Pacific Convention.

A considerable number of conferences have been held by members of the committee, as a result of which it is planned to present at the October meeting in New York a number of papers on appraisal work and a topical discussion on methods of keeping inventories and appraisals up to date.

In view of the wide variety of opinions concerning inventory and appraisal work, the committee believes that it is not wise to attempt to present anything in the nature of a complete report but recommends the continuance of the committee in order that further study and investigation may be made of this important subject.

Educational Committee.—The Educational Committee has decided to begin the preparation of a list of topics suitable for advanced study, research and invention in electrical engineering. This was considered to be a piece of work which might be of benefit to colleges of engineering, and at the same time of such a technical nature as to be outside of the scope of activity of various educational associations. It is felt that work of this kind might well be made a part of the regular duties of the Educational Committee or one of its sub-committees. The committee would thus in time establish closer relations with colleges of engineering, research laboratories and individual investigators, and would become a center of information and a source of wholesome inspiration for electrical research in this country. A list of topics for research with some suggestions, compiled by the chairman of the committee, has been accepted for presentation at the Annual Convention.

Editing Committee.—The Editing Committee has had general supervision over the discussions in the PROCEEDINGS and the contents of the TRANSACTIONS published during its incumbency. The method of handling this material has been the same as in the previous two or three years and it appears to have met with general satisfaction. The only important typographical changes which have been adopted for the current year have been the new style for the cover and the combination of the Section I and Section II tables of contents on the first page of the PROCEEDINGS immediately inside the cover.

Committee on Development of Water Power.—During the past year this committee, through its members, has endeavored to keep informed respecting the progress of legislation affecting water power development and other allied questions. The committee has held several meetings, a large number of informal conferences, and has exchanged much correspondence.

In the fall of 1915 the committee accepted an invitation from Governor James Withycombe of the State of Oregon to send a delegate to address a Western Water Power Conference held at Portland, Oregon, September 21, 22 and 23. Mr. John H. Finney, a member of the committee, was appointed and presented to the conference a brief which had been prepared by the committee.

Acting jointly with the Meetings and Papers Committee, this committee arranged for the special Institute meeting held in Washington, D. C., under the auspices of the Washington Section, on April 26, at which various aspects of the water power situation were treated through the medium of a carefully prepared program.

Public Policy Committee—The Public Policy Committee has held four meetings during the year, at which various matters referred to the committee were considered and discussed. Among the more important questions reported upon by the committee to the Board of Directors were the following: Legislation providing for federal support for engineering experiment stations in each state; water power legislation; engineering cooperation; translation of standardization rules into foreign languages: legislation affecting the engineering profession.

Committee on Relations of Consulting Engineers.—On May 13, 1915, the committee submitted to the Board of Directors a proposed schedule

of fees as a general guide for consulting engineers. No other matters have developed requiring the attention of the committee.

U. S. National Committee of the International Electrotechnical Commission—The War has naturally interfered with the international activities of the Commission, but nevertheless a considerable amount of work has been carried on among the individual national committees.

In America, electrical engineering standardization has been confined to the work of the A. I. E. E. Standards Committee. The British Standardization Rules for Electrical Machinery have been published during the year, and are believed to be in substantial conformity with the last edition (1915) of the A. I. E. E. Standardization Rules, as well as with the international rules thus far adopted by the I. E. C.

The Annual Report of the Honorary Secretary of the Commission, dated January 1916, which has been received from the Central Office, indicates that the work of the Commission, in abeyance for the present, should be expected to recontinue as soon as the peace of the world shall have been restored.

The U. S. National Committee held one meeting, in New York, in November 1915.

Constitutional Revision Committee.—The Constitutional Revision Committee was appointed at the beginning of the administrative year, and immediately began work upon the revision of the constitution. All suggestions which had been received since the last amendment to the constitution in 1912 were considered by the committee. Requests for further suggestions were made to each member of the present Board of Directors, each past-president, and each Section chairman. As the result of the suggestions received and those made by the members of the committee the proposed amendments were agreed upon and submitted to the Board of Directors in December 1915. The amendments are now being voted upon by the membership and the result of the vote will be made known at the Annual Meeting.

Employment Department.—The usefulness of the Employment Department has increased greatly during the year. A considerable number of Institute members have been helped to positions, and employers are more and more taking advantage of the facilities offered by the Institute for placing them in touch with desirable technical men. The Institute continues to publish without charge in the monthly PROCEEDINGS announcements of vacancies and men available.

Board of Examiners.—The Board of Examiners has held 11 meetings during the year. It has considered and referred to the Board of Directors with its recommendations a total of 1,419 applications of all kinds. In addition to these, the Board has reviewed 29 applications for a second and third time. Although the total number of applications is less than last year, the amount of time devoted to the work by the Board was considerably greater this year. The reason for this is that there were less applications for admission as Associates, which require very little detailed examination, but more applications for the higher grades, to which much time must necessarily be devoted. In considering applications for admission and transfer to the grade of Fellow the Board has adhered rigidly to its interpretation of the constitutional requirements, as may be

inferred from the following figures showing that only 10 applicants were recommended for this grade, and 20 were not recommended.

APPLICATIONS FOR ADMISSION.

Recommended for grade of Associate	624	
Not recommended for grade of Associate	1	625
Recommended for grade of Member	44	
Not recommended for the grade of Member	14	58
Recommended for grade of Fellow	3	
Not recommended for Fellow	5	8
Recommended for enrolment as students	643	643

APPLICATIONS FOR TRANSFER.

Recommended for grade of Member	54	
Not recommended for grade of Member	9	63
Recommended for grade of Fellow	7	
Not recommended for grade of Fellow	15	22
Total number of applications considered		1419
Applications reconsidered		29
Admission and transfer all grades		1448

Membership Committee.—The work of the Membership Committee began early last fall when plans were formulated assigning a definite portion of the work to each member of the committee. This, based upon well established precedent, aimed to increase the membership without the employment of undignified methods. Later it was decided to extend operations in the same and new fields.

The work of the committee, into which the individual members entered with considerable interest and activity, resulted in the filing of 777 applications for membership, and the laying of a foundation for the work of the succeeding committee.

The Membership Committee, believing its duty to be the retention of existing as well as the acquisition of new members, has during the year cooperated with the Secretary of the Institute in securing the payment of dues in arrears, and, in general, seeking and endeavoring to remove the cause of difficulty. So much has been accomplished that it is urgently recommended that this function be delegated to the Membership Committee each year.

The following tabulated statement shows the number of members in each grade, the total membership, and the additions and deductions that have been made during the year:

	Honorary Member	Fellow	Member	Associate	Total
Membership, April 30, 1915.	5	448	1079	6522	8054
Additions:					
Elected	....	4	41	584	....
Transferred	....	6	47	....	....
Reinstated	....	....	7	46	....
Deductions:					
Died	....	2	7	27	....
Resigned	....	....	13	206	....
Dropped	....	2	13	254	....
Transferred	....	....	4	49	....
Membership, April 30, 1916.	5	454	1137	6616	8212

Net increase in membership during the year.................................... 158

Deaths.—The following deaths have occurred during the year:

Fellows.—Henry A. Mavor, Louis Duncan.

Members.—Fred S. Pearson, Max Hebgen, C. E. Hogle, R. A. McKee, James I. Ayer, W. W. Cole, W. C. Robinson.

Associates.—J. A. Culverwell, I. W. Moore, O. C. F. Hague, J. F. McElroy, E. J. Correa, R. W. Farr, Eugene Fischer, W. J. Henry, Geo. F. Kenyon, Joseph Herzog, John W. Barnett, R. C. Watson, Wm. F. Endress, Roy N. Wooster, Crellin Cartwright, W. C. Andrews, James S. Anthony, W. G. Roome, Frank Zencak, W. E. Dickinson, F. H. Varney, E. F. Cannon, J. Ray Wilson, C. J. H. Woodbury, John C. Manley, Chas. F. Baldwin, George H. Stockbridge. Total deaths, 36.

Finance Committee.—The following correspondence and financial statements form a complete summary of the work of the Finance Committee for the year.

Board of Directors, New York, May 12, 1916
American Institute of Electrical Engineers.

Gentlemen:

Your Finance Committee respectfully submits the following report for the year ending April 30, 1916.

During the past year the committee has held monthly meetings, has passed upon the expenditures of the Institute for various purposes and otherwise performed the duties prescribed for it in the Constitution and By-Laws. Haskins & Sells, certified public accountants, have audited the books, and their certification of the Institute finances follows.

In company with your Treasurer, Secretary, and a member of the firm of accountants, the committee has examined the securities held by the Institute and finds them to be as stated in the accountants' report.

In accordance with the recommendation of your committee in their report dated May 11, 1915, the Board of Directors instructed the Finance Committee to liquidate the mortgage upon the lands on which the Engineering Societies Building stands. This mortgage, amounting to **$54,000.00**, was paid June 25, 1915, and therefore the Institute is now free from all indebtedness save for current liabilities as shown in the accompanying report.

Respectfully submitted,

(Signed) J. Franklin Stevens,
Chairman, Finance Committee.

HASKINS & SELLS

CERTIFIED PUBLIC ACCOUNTANTS
30 BROAD STREET
NEW YORK

CABLE ADDRESS "HASKSELLS"

WATERTOWN
BALTIMORE
PITTSBURGH
CLEVELAND
CHICAGO
ST. LOUIS
ATLANTA
DENVER
SAN FRANCISCO
LONDON, E. C.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

CERTIFICATE

We have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1916, and

We Hereby Certify that the accompanying General Balance Sheet properly sets forth the financial condition of the Institute on April 30, 1916, that the Statement of Income and Profit & Loss for the year ended that date is correct, and that the books of the Institute are in agreement therewith.

HASKINS & SELLS
Certified Public Accountants.

New York
May 12, 1916.

AMERICAN INSTITUTE OF

General Balance Sheet

Exhibit A.

Assets.

Land and Building:			
Interest in United Engineering Society's Real Estate No. 25 to 33 West 39th Street:			
Building		$353,346.61	
Land (One-third of Cost)		180,000.00	
Total Land and Building			$533,346.61
Equipment:			
Library—Volumes and Fixtures		$ 39,217.30	
Works of Art, Paintings, etc		3,001.35	
Office Furniture and Fixtures		11,229.48	
Total		$ 53,448.13	
Less Reserve for Depreciation		6,989.01	
Remainder—Equipment			$ 46,459.12
Investments:			
Bonds—City of Wilmington, Delaware, 4½%, 1934, Par $15,000			$ 15,938.83
Working Assets:			
Publications entitled "Transactions," etc		$ 10,908.50	
Badges		602.95	
Total Working Assets			$ 11,511.45
Current Assets:			
Cash		$ 6,740.09	
Accounts Receivable:			
Members, for Entrance Fees and Past Dues		7,750.00	
Advertisers		446.70	
Miscellaneous		580.94	
Interest Accrued—Investments		56.25	
Interest Accrued—Bank Balances		107.73	
Total Current Assets			$ 15,681.71
Funds:			
Life Membership Fund:			
Cash	$ 349.89		
Chicago, Burlington & Quincy Railroad Company, 4%, 1958, Par $5,000.00	4,868.75		
Interest Accrued	33.33	$ 5,251.97	
International Electrical Congress of St. Louis—Library Fund:			
Cash	$ 756.39		
New York City Bonds, 4½%, 1957, Par $2,000.00	2,261.47		
Interest Accrued	45.00	3,062.86	
Mailloux Fund:			
Cash	$ 104.10		
New York Telephone Company Bond, 4½%, 1939	1,000.00		
Interest Accrued	22.50	1,126.60	
Midwinter Convention Fund—Cash		158.93	
Total Funds			9,600.36
Total			$632,538.08

ELECTRICAL ENGINEERS

APRIL 30, 1916

LIABILITIES

CURRENT LIABILITIES:		
Accounts Payable—Subject to Approval by the Finance Committee	$ 7,146.64	
Dues Received in Advance	1,322.97	
Entrance Fees and Dues Advanced by Applicants for Membership	455.50	
Total Current Liabilities		$ 8,925.11
FUND RESERVES:		
Life Membership Fund	$ 5,251.97	
International Electrical Congress of St. Louis—Library Fund	3,062.86	
Mailloux Fund	1,126.60	
Midwinter Convention Fund	158.93	
Total Fund Reserves		9,600.36
SURPLUS: Per Exhibit "B"		614,012.61
Total		$632,538.08

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

STATEMENT OF INCOME AND PROFIT AND LOSS

FOR THE YEAR ENDED APRIL 30, 1916

EXHIBIT B.

REVENUE:			
Entrance Fees		$ 3,565.00	
Dues		87,695.28	
Student's Dues		4,621.50	
Transfer Fees		520.00	
Advertising		8,049.43	
Subscriptions		2,688.38	
Sales of "Transactions," etc.		2,323.86	
Badges Sold	$1,684.00		
Less Cost	1,475.05		
		208.95	
Interest on Investments		965.97	
Interest on Bank Balances		533.92	
Exchange		27.53	
Total			$111,199.82
EXPENSES:			
Meetings and Papers Committee:			
Salaries		$ 5,425.00	
Binding and Mailing Proceedings		6,426.13	
Printing Proceedings		11,121.75	
Engraving Proceedings		2,349.12	
Paper and Cover Paper		6,320.34	
Envelopes		786.83	
Stationery and Miscellaneous Printing		89.95	
General Expenses		128.23	
Meetings		5,983.43	
Volume No. 32		5.90	
Volume No. 33		12,422.92	
Volume No. 34		1,476.64	
Total		$ 52,536.24	
Deduct Increase in Inventory of Publications:			
May 1, 1915	$ 9,650.75		
April 30, 1916	10,908.50	1,257.75	$ 51,278.49
Executive Department:			
Salaries		$ 16,448.50	
General Expenses		1,980.06	
United Engineering Society—Assessments		4,800.00	
Express		412.59	
Postage		2,710.56	
Advertising		2,035.76	
Stationery and Miscellaneous Printing		3,111.67	
Year Book and Catalogue		2,750.85	
Interest on Bond and Mortgage		360.00	34,609.99
FORWARD		$	$ 85,888.48
REVENUE—(Forward)			$111,199.82

Revenue—(Forward)		$111,199.82
Expenses—(Forward)		$ 85,888.48
Sections Committee:		
Section Meetings	$ 5,338.94	
Branch Meetings	162.33	
Delegates' Convention Expenses	1,574.05	
Salaries, New York Office	2,340.00	
Stationery and Printing, New York Office	647.00	
Express on Advance Copies	43.94	
		10,106.26
General:		
Library Committee	$ 3,999.99	
Membership Committee	890.55	
Finance Committee	150.00	
Standards Committee	363.41	
Code Committee	73.45	
International Engineering Congress, 1915	750.00	
Reception Committee, International Engineering Congress 1915	224.17	
Constitutional Revision Committee	695.50	
Library Research Department	250.00	
Salary and Traveling Expenses, Honorary Secretary	4,440.17	11,837.24
Total		$107,831.98
Add:		
Increase in Accounts Payable—Subject to Approval of Finance Committee, Expenses Undistributed at:		
May 1 1915, not including liability for badges sold or on hand, $70.00	$ 4,979.41	
April 30, 1916	7,146.64	2,167.23
Total Expenses		$109,999.21
Net Revenue:		$1,200.61
Profit & Loss Credits—Accessions to Library Volumes and Fixtures	$ 681.25	
Land, Building, and Endowment Fund Transferred to the General Fund	7,807.10	
Charged to Mailloux Fund on Account of Payment from General Fund in December, 1914, which should have been paid from Mailloux Fund	50.75	
Payment Received for Tickets to Annual Function, February 1915	10.50	
Adjustment of Office Furniture and Fixtures, Applicable to Prior Period	466.50	9,016.10
Gross Surplus for the Year		$ 10,216.71
Profit & Loss Charges:		
Uncollectible Dues Written Off	$ 3,403.00	
Provision for Depreciation of Furniture and Fixtures	1,267.06	
Loss on Sale of Securities	1,763.85	
Amortization of Premium on City of Wilmington, Delaware, 4½% Bonds of 1934	58.67	
Total		6,492.58
Net Surplus for the Year		$ 3,724.13
Surplus, May 1, 1915		610,288.48
Surplus, April 30, 1916		$614,012.61

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Statement of Cash Receipts and Donations for Designated Purposes. Also Disbursements, for the Year Ended April 30, 1916.

Exhibit C.

Receipts:	
Land, Building and Endowment fund—Interest	$104.62
Life Membership Fund—Interest	206.63
International Electrical Congress of St. Louis Library Fund—Interest and Royalties	97.65
Mailloux Fund—Interest	45.00
Midwinter Convention Fund	158.93
Total	$612.83
Disbursements:	
Land Building and Endowment Fund—Account payment of mortgage on land, 25-33 West 39th Street, New York City	$7807.10
Life Membership Fund	269.38
Mailloux Fund	54.95
Total	$8131.43

RECEIPTS AND DISBURSEMENTS PER YEAR PER MEMBER.

During each fiscal year for the past eight years.

Year ending April 30	1909	1910	1911	1912	1913	1914	1915	1916
Membership, April 30, each year	6400	6681	7117	7459	7654	7876	8054	8212
Receipts per Member	$13.21	$13.35	$13.37	$13.19	$13.45	$14.08	$14.06	$13.62
Disbursements per Member	10.49	12.03	11.03	12.44	15.57	12.86	13.54	13.74
Credit Balance per Member	$2.72	$1.32	$2.34	$ .75	*$2.12	$1.22	$ .52	*$ .12

*Deficit.

Respectfully submitted for the Board of Directors,

F. L. HUTCHINSON, *Secretary.*

New York, May 16, 1916.